Continuing Education in Engineering
University Extension
University of California, Berkeley

X476.1 INTRODUCTION TO WIRELESS NETWORKS

Summer 2003

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COURSE OBJECTIVE:

To provide a basic understanding of the types and characteristics of major wireless communications networks in use around the world, and an insight into emerging wireless networks.

REQUIRED READING:

Weekly handout materials.

RECOMMENDED REFERENCES:

- Paul Bedell, *Wireless Crash Course*, McGraw-Hill, 2001.
- William Stallings, *Wireless Communications & Networks*, 1st Edition, (Prentice-Hall, August 2001)

COURSE GRADING:

Attendance	10%	Each unexcused absence will result in a 1 percentage point deduction from this performance criterion
Participation	10%	
Class Exercises	40%	Based on 4 open-book tests, each worth 10%
Final Exam	40%	Will encompass all material covered in the course

GRADING SCALE:

A+: 95 -100%	**A: 90 – 94%**	**B+: 85 – 89%**	**B: 80 – 84%**	**B-: 75 – 79%**
C+: 70 – 74%	**C: 65 – 69%**	**C-: 60 – 64%**	**D: 50 – 59%**	**F: <50%**

CLASS SCHEDULE AND TOPICS OF DISCUSSION

06-11-03	Class Overview and Introduction Introduction to Wireless Communications
06-18-03	Wireless Terminologies and Definitions ***Class Exercise #1***
06-25-03	Introduction to Cellular Mobile Communications
07-02-03	Major Cellular Mobile Communication Systems ***Class Exercise #2***
07-09-03	Wireless Local Loop and Broadband Wireless Systems
07-16-03	Satellite Communication Networks ***Class Exercise #3***
07-23-03	Radio Paging and Messaging Networks
07-30-03	Wireless Local Area Networks
08-06-03	Emerging Personal Area Networks ***Class Exercise #4***
08-13-03	Course Review ***Final Exam***

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Final Exam August 13, 2003

Student Name:_____

A). Answer True (T) or False (F):

T 1. Wireless communication systems use radio waves or infrared technology for the connection between the transmitter and receiver.
T 2. Wireless communication systems can be terrestrial based or satellite based.
T 3. An electromagnetic wave traveling through the air/space transfers power through its orthogonal electric (E) and magnetic (H) fields.
T 4. Electromagnetic waves travel through the air at a speed approximately equal to the speed of light. (in vacumm)
T 5. Europe's DECT system is an example of a portable communication system.

F 6. Fixed wireless systems are not appropriate for high-speed data applications.
T 7. Point-to-point microwave systems are examples of fixed wireless systems.
F 8. Transportable cellular telephones are fairly common nowadays.
T 9. Small satellite dishes such as used for dish TV have been made possible by the use of very high frequencies. (p15)
F 10. Higher frequencies are generally preferred for mobile communication applications. Lower

T 11. The frequency band between 30 GHz and 300 GHz is referred to as the *millimeter wave* band.
T 12. Operational cellular/PCS systems around the world operate in the UHF band.
T 13. Most major wireless communication systems use RF technology for over-the-air communications. + infrared frequency
T 14. Time Division Duplexing (TDD) is very sensitive to timing and works only with digital transmission formats. and analogy
T 15. Frequency Division Duplexing (FDD) is used only in analog wireless systems. (p3)

F 16. Assuming CDPD to be a 1.5G technology, all major first generation cellular systems were based on analog FM technology. Digital (v) based on Digital
T 17. Digital technology enables more efficient and reliable support of wireless data services.
F 18. Second generation digital cellular systems around the world are based on TDMA

technology.

T 19. Third generation (3G) wireless systems around the world currently operate in a common globally-allocated frequency band.

T 20. WLL systems are used as alternatives to subscriber lines that interconnect subscriber premises to the Telco switched infrastructure.

T 21. MMDS is also referred to as "wireless cable".

F 22. An LMDS transmitter can cover a wider range than an MMDS transmitter.

T 23. LMDS can support much higher data rates than MMDS.

F 24. A set of three properly positioned satellites in the LEO orbit can adequately cover the earth's surface.

F 25. In LEO and MEO satellite systems, "cells" created on the ground by the satellites appear stationary relative to users on the earth.

T 26. GEO-based satellite systems are preferred for fixed applications.

T 27. The higher the altitude of a satellite the longer it takes for the satellite to go around the earth.

F 28. In satellite paging, pagers receive paging messages directly from the satellite.

T 29. FLEX is currently the most popular paging technology in all new paging system installations around the world.

T 30. In the US, ARDIS wireless messaging service has wider coverage than Mobitex service.

T 31. iMode is a wireless Internet service that is highly popular in Japan.

T 32. Cellular SMS is currently the most popular wireless messaging service in the world.

F 33. Because WLAN systems are deployed in the unlicensed frequency bands, interference to these systems is not an issue.

T 34. The DHCP server assigns IP addresses to computers on the WLAN.

F 35. IEEE 802.11b WLAN products support higher data rates than IEEE 802.11a products.

T 36. Products based on the new IEEE 802.11g standard will be backward compatible with the 802.11a and 802.11b systems.

T 37. The most common applications of Bluetooth technology are expected to use low power (1 mW) devices.

F 38. Bluetooth radios use direct sequence spread spectrum (DS-SS) technology.

F 39. Bluetooth requires that communicating devices have a line-of-sight clearance between them.

F 40. Bluetooth networks are limited to eight devices.

B). Circle the one correct answer to each of the following statements:

1. The following are all examples of wireless communication systems except _____.
   a) Local area networks (LANs).
   b) Microwave radio systems.
   c) TV remote control systems.
   d) Mobile-satellite communication systems.
   e) Fixed wireless access systems.

2. Of all types of wireless communication systems, these are better suited for broadband applications.
   a) Mobile communication systems
   b) Portable communication systems
   c) Fixed wireless systems
   d) Transportable communication systems

3. The following statements are true about electromagnetic (EM) waves except statement ____.
   a) EM waves propagate through the air at a speed of about 3×10^8 m/sec
   b) Wireless communication signals are transported over the air using EM waves.
   c) A higher frequency EM signal can penetrate through objects better than a lower frequency signal.
   d) A lower frequency EM signal requires a larger antenna to efficiently radiate into the air/space than a higher frequency signal.
   e) A lower frequency EM signal requires lower transmit power to achieve the same range as a higher frequency signal.

4. The radio frequency (RF) band of the electromagnetic spectrum includes all frequencies up to _____.
   a) 3 kHz
   b) 144 MHz.
   c) 1 GHz
   d) 300 GHz
   e) 100 THz

5. In a wireless system, this network component is used to provide wireless interface to user devices.
   a) Base Station (BS)
   b) Cell Site (CS)
   c) Network Switching Center (NSC)
   d) Network Control Center (NCC)

6. To transmit a digital signal over analog facilities, the signal must first be _____ .
   a) Digitized.
   b) Encoded.
   c) Modulated.
   d) Decoded.

7. In this mode of communication, transmission can occur in both directions simultaneously.
   a) Simplex communication mode.
   b) Half-duplex communication mode.
   c) Full-duplex communication mode.
   d) All of the above.

8. In mobile communication systems using paired channels, the network base stations normally transmit using the higher frequencies so that _____ .
   a) The range of base station transmitters can be made large.
   b) The mobile station transmit power requirements can be minimized to enable the design of lightweight user devices.
   c) The base station antennas can be kept small to avoid zoning problems in some municipalities.
   d) The mobile station antennas can be kept small.

9. In this traffic channel sharing technique, all users can transmit on the same radio channel at the same time.
   a) CSMA
   b) CDMA
   c) FDMA
   d) TDMA

10. The primary reason that the CSMA/CD channel sharing scheme cannot be used in wireless systems is that _____ .
   a) CSMA/CD is dedicated to wired local area networks (LANs).
   b) CSMA/CD cannot achieve as high throughput as other schemes.
   c) CSMA/CA is more efficient than CSMA/CD.
   d) It is not feasible for wireless devices to monitor outgoing transmissions.
   e) None of the above.

11. In cellular mobile telecommunication systems, the _____ is the entity that is central to network call processing.

a) VLR
b) Network Control Center (NCC)
c) MTSO (MSC)
d) Base Station (BS)
e) Base Station Controller (BSC)

12. Wireless systems based on cellular design can achieve much higher traffic capacity than non-cellular designs because _____.
    a) Cellular designs use frequency re-use in close proximity.
    b) Cellular designs use higher power transmitters.
    c) Cellular designs permit operation at higher noise levels.
    d) Non-cellular designs do not re-use frequencies.
    e) All of the above.
    f) Only (a) and (d) above.

13. In a cellular system with a total of 120 channels and using a cluster size of 3, each cell in the system can be allocated up to _____ traffic channels.
    a) 3
    b) 7
    c) 12
    d) 40
    e) 120

14. The following statements are true about major first generation cellular systems except statement _____.
    a) Systems were all based on analog radio transmission technology.
    b) Systems developed in Europe were incompatible with the AMPS system developed in the US.
    c) European systems were compatible with each other and allowed intersystem roaming.
    d) Systems were primarily used for voice communication.

15. One of the primary reasons for the development of second generation (digital) cellular systems was to _____.
    a) Enable easy integration of cellular systems with digital services offered in the PSTN.
    b) Make use of newly-discovered digital transmission technologies.
    c) Enhance system quality.
    d) Enable more efficient transport of data services.
    e) All of the above.

16. The following statements are true about the PHS and PDC digital cellular systems except statement _____.
    a) Both standards are in use in Japan.
    b) Both standards are based on TDMA multiple access scheme.
    c) The two systems are compatible and support intersystem call handoffs.

17. Of the cellular standards developed in the US, the one seen as having an easier upgrade path to 3G services is _____.
    a) AMPS
    b) D-AMPS.
    c) cdmaOne.
    d) CDPD.

18. The following statements are true about the GSM digital cellular system technology except statement _____.
    a) GSM was invented in Europe.
    b) GSM is in use in the US.
    c) GSM uses CDMA multiple access scheme.
    d) GSM data handling capability can be enhanced using GPRS and EDGE upgrades.

19. A major reason why the ITU goal of achieving a single global wireless standard for 3G systems has not been achieved so far is because _____ .
    a) Some countries prefer not to adopt ITU recommendations.
    b) It has not been possible so far to align all regions of the world under a single radio interface standard.
    c) The radio spectrum required for such a global system is too wide for some countries to dedicate to one service.
    d) Some countries have not exhausted the capacities of existing cellular systems and see no need for adopting a new standard at this moment.
    e) All of the above.

20. The two ITU-R air interface standards which are expected to dominate the 3G network space are _____ .
    a) IMT-DS and IMT-MC.
    b) IMT-MC and IMT-TC.
    c) IMT-TC and IMT-SC.
    d) IMT-SC and IMT-FT.
    e) IMT-FT and IMT-DS.

Wireless Local Loop

21. The following statements are true about WLL systems except statement _____.
    a) WLL systems are fixed wireless systems used in the local loop as alternatives to copper wire, coaxial cable and optical fiber.
    b) Some in the industry use WLL to represent all fixed wireless distribution systems, including LMDS and MMDS systems.
    c) WLL systems are very commonly used for telephony service distribution in major metropolitan areas.
    d) WLL systems can be used for both residential and business customers.

22. An LMDS system is generally more expensive to deploy than an MMDS system covering the same area because _____.
    a) MMDS is a more mature technology, enjoying the benefit of lower cost components.
    b) LMDS systems operate at higher frequencies and therefore typically require more cells to cover an area.
    c) MMDS cannot support as high data rates as possible with LMDS. p16
    d) All of the above.
    e) Only (a) and (b) above.
    f) Only (b) and (c) above

23. Air interface specifications for MMDS systems in the US are covered under the ___ standard.
    a) IEEE 802.16.1
    b) IEEE 802.16.2
    c) IEEE 802.16.3 p14
    d) None of the above.

24. The following statements are true about MMDS and LMDS except statement _____.
    a) Both MMDS and LMDS systems can support 2-way digital communications.
    b) LMDS is capable of delivering more services than MMDS.
    c) Cost considerations currently make MMDS preferred over LMDS for some applications.
    d) MMDS and LMDS systems do not require line-of-sight path with customer premises.
    e) Both LMDS and MMDS are fixed broadband wireless access services.

25. Of MMDS and LMDS systems in the US, the one that has been allocated a much larger amount of radio frequency spectrum is _____.
    a) LMDS 27-31GHz
    b) MMDS 2GHz

26. In general, antennas for Ka-band satellite systems are much smaller than those for C-band systems because _____.

a) The Ka-band, being the newest band allocated to satellite communications, employs more modern technology.
b) The Ka-band does not yet have as much traffic as the C-band.
c) The Ka-band is a much higher frequency band than the C-band.
d) The Ka-band does not support high speed applications.
e) All of the above.

27. The following statements are true about the geostationary orbit except statement ____.

a) The geostationary orbit is at an altitude of about 36,000 km above the equator.
b) At this altitude, communication signals incur a one-way propagation path delay of about 270 msec.
c) A set of three properly positioned satellites in this orbit can provide total coverage of the earth's surface.
d) This orbit is used by many countries to deploy domestic and regional satellite systems.

28. Satellite systems based on the LEO and MEO orbits are generally preferred for land mobile communications because _____.

a) Less power is required for hand-held user devices on the ground to reach the satellite.
b) Satellites in these orbits are smaller and easier to operate and maintain.
c) Satellites in these orbits use regenerative transponders.
d) Satellites in these orbits can truly provide global coverage.
e) Both (a) and (d) above.

29. In comparing GEO-based satellite systems with those in LEO and MEO orbits, the following statements are true except statement _____ .

a) GEO satellite systems use much lower transmit power.
b) GEO satellites circle the earth once each day whereas LEO and MEO satellites go around the earth many times a day.
c) LEO and MEO systems use radio spectrum more efficiently.
d) LEO and MEO satellite systems require many satellites to cover the earth.

30. In a two-way (interactive) paging system, _____ .

a) Users are provided two pagers: one for receiving pages, the other for transmitting messages.
b) The network uses two sets of antennas: a set of high-power antennas for transmitting to pagers, and a set of many low-height antennas for receiving messages from them.

c) Response messages are always sent using keyboards.
d) Both (b) and (c) above.

31. The following statements are true about the Mobitex and ARDIS wireless messaging systems except statement _____.
    a) They are both in use in the US, Europe and in Asia.
    b) They both use proprietary air interface protocols.
    c) They both provide access to users' corporate host computers.
    d) In the US, Mobitex systems are deployed in the 900 MHz band whereas ARDIS systems use spectrum in the 800 MHz band.

32. The following statements are true about cellular SMS service except statement _____.
    a) SMS use is more widespread in Europe than it is in the US.
    b) SMS messages are carried over the cellular system's control channels.
    c) SMS was first incorporated in the GSM digital cellular standard, but is now available in D-AMPS, cdmaOne and PDC networks as well.
    d) SMS roaming in North America is widely available.

33. The following statements are true about WLANs except statement _____.
    a) Stations on a WLAN use low power wireless transceivers for communicating on the network.
    b) Both workstations and servers can be connected wirelessly in a WLAN.
    c) Most WLAN products on the market today use diffused beam infrared technology.
    d) WLANs offer users convenience and flexibility that is not possible with standard wired LANs.

34. The component that needs to be installed in a PC to enable it to communicate wirelessly in a WLAN environment is the _____.
    a) Access Point (AP).
    b) Wireless NIC.
    c) PCMCIA card.
    d) LAN network interface card (NIC).

35. The term *Wi-Fi* is being used in the industry to refer to _____.
    a) All wireless LAN systems.
    b) Wireless LAN systems based on the IEEE 802.11 standards.
    c) IEEE 802.11a WLAN systems.
    d) IEEE 802.11b WLAN systems

36. One of the primary reasons that WLANs designed for the 5 GHz band have not been widely adopted in the marketplace is that _____.

a) The products in this frequency band are much larger than those in the 2.4 GHz band.
b) The products in this band are based on frequency hopping spread spectrum (FH-SS) technology.
c) The products in this band cannot support high data rates.
d) The products in this band are currently more expensive than those in the 2.4 GHz band.
e) The products in this band are more difficult to operate and maintain.

37. In Bluetooth PANs, the term "unconscious connectivity" is used to describe _____.

a) The ability of Bluetooth devices to join more than one piconet at a time.
b) The ability of each Bluetooth device to perform as a master or as a slave in a piconet.
c) The ability of Bluetooth devices to maintain communication order under control of the piconet master.
d) The ability of Bluetooth devices to join piconets without user interaction.

38. Voice communication in Bluetooth systems is carried over _____ connections.

a) Synchronous.
b) Asynchronous.
c) Packet-switched.
d) Voice profile.

39. The throughput of Bluetooth SCO links is far below the 1 Mbps theoretical data rate because _____.

a) Transmissions over the TDD channel are performed in 625 μsec time slots.
b) Actual information payload transmitted over each time slot is only 240 bits.
c) Some time has to be allocated in each time slot for the radios to perform frequency hopping.
d) The bandwidth of Bluetooth radio channels cannot support a 1 Mbps throughput.
e) All of the above.
f) Only (b) and (c) above.

40. The profile which is seen as potentially the most useful of all Bluetooth service profiles is the _____ profile.

a) File transfer.
b) Generic access.
c) Cordless telephony.
d) Generic object exchange.
e) LAN access.

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Class Exercise #4 August 6, 2003

Student Name:_____

A). Answer True (T) or False (F):

_____ 1. The very first radio paging systems supported tone-plus-voice paging.
_____ 2. Two-way paging systems use the same antennas for transmitting to pagers and receiving messages from them.
_____ 3. The ARDIS and Mobitex wireless messaging systems are in use in the US and in many countries in Europe and Asia.
_____ 4. iMode is the most popular wireless messaging service in the world.
_____ 5. All wireless LANs are based on the IEEE 802.11 standards.
_____ 6. IEEE 802.11a WLANs can support higher data rates than IEEE 802.11b products.
_____ 7. Until recently, many in the industry considered HIPERLAN/2 products as the biggest competitor to IEEE 802.11b products.
_____ 8. Bluetooth uses infrared technology to provide short-range wireless interconnectivity between devices.
_____ 9. Version 1 of the IEEE 802.15.1 standard was derived from the Bluetooth 1.0 specification.
_____ 10. The Bluetooth SIG Promoters group currently consists of nine member companies.

B). Circle the one correct answer to each of the following statements:

1. The following statements are true about radio paging and wireless messaging systems except statement _____.
   a) Both systems use cellular-like frequency planning.
   b) Both systems carry data rather than voice traffic.
   c) Both systems can support two-way data communications.
   d) Radio paging systems generally handle shorter messages than wireless messaging systems.

2. The _____ technology is used to provide 2-way paging service.
   a) POCSAG
   b) ReFLEX
   c) RPC1

3. The following statements are true about the Mobitex and ARDIS wireless messaging systems except statement _____.
   a) Mobitex was invented in Europe whereas ARDIS originated in the US.
   b) Both systems transmit at the same data rate.
   c) Both systems are in use in the US.
   d) Both air interface protocols are open protocols.

4. Cellular SMS service is different from iMode service because _____.
   a) SMS service is offered over digital cellular networks.
   b) SMS is not intended to be a wireless Internet service.
   c) SMS is a data-only (non-voice) service.
   d) SMS is not being used in Japan
   e) Both (b) and (d) above.

5. In a wireless LAN, the device that contains the traditional base station radio function on the network side is the _____ .
   a) Access Point
   b) DHCP
   c) Router
   d) File Server

6. Most operational IEEE 802.11 WLAN installations around the world today are based on _____ technology.
   a) Frequency hopping spread spectrum (FH-SS).
   b) Corded orthogonal frequency division multiplexing (COFDM).
   c) Infrared.
   d) High rate direct sequence spread spectrum (HR/DS-SS).
   e) None of the above.

7. Compared to IEEE 802.11a WLAN products, the IEEE 802.11b WLAN products are more popular around the world because _____.
   a) They support higher data rates.
   b) They are less complex to operate and maintain.
   c) They support data rates comparable to wired Ethernet LANs and are backward compatible with the older IEEE 802.11 (DS-SS) products.
   d) They are less expensive.
   e) Both (c) and (d) above.

8. Some in the industry refer to Bluetooth radios as "rude" radios because _____.
   a) Bluetooth radios originated from Europe.
   b) Bluetooth radios do not use DS-SS technology.
   c) Bluetooth radios do not comply with FCC radio emission standards
   d) Bluetooth radios use a very high hopping rate which is almost guaranteed to cause interference to other systems in the band.
   e) Bluetooth radios have a high probability of causing accidental hop synchronization between unintended devices within range of each other.

9. The true throughput of a Bluetooth SCO radio link is _____ .
   a) 1 Mbps.
   b) 625 kbps.
   c) 384 kbps.
   d) 259 kbps.
   e) 144 kbps.

10. The _____ profile is required to be included in every Bluetooth device.
   a) LAN access.
   b) Synchronization.
   c) Serial port.
   d) Generic access.
   e) Service discovery application.

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Class Exercise #3 July 9, 2003

Student Name: Ya-Cheng Shih

A). Answer True (T) or False (F):

T 1. Twisted-pair copper wires are the standard local loop facilities used to connect residential customer premises to the telephone company's switched telephone network.
F 2. WLL systems are used as alternatives to wired trunks that interconnect Telco switches.
T 3. LMDS can support much higher data rates than MMDS.
F 4. LMDS is also referred to as "wireless cable".
T 5. An MMDS transmitter can cover a wider range than an LMDS transmitter.
T 6. It takes about a day for a satellite in GEO orbit to make one revolution around the earth.
F 7. The lower the altitude of a satellite the longer it takes for the satellite to go around the earth.
T 8. The higher the altitude used the more the number of satellites required to cover the earth.
F 9. LEO and MEO satellites are preferred over GEOs for fixed applications.
F 10. Long distance telecommunications services within most countries are provided through the INTELSAT satellite system.

B). Circle the one correct answer to each of the following statements:

1. An MMDS system is generally cheaper to deploy than an LMDS system covering the same area because _____.
   A
   a) MMDS is a more mature technology, enjoying the benefit of lower cost components.
   b) MMDS systems operate at lower frequencies and can therefore make use of much larger cells than those possible with LMDS.
   c) MMDS cannot support as high data rates as possible with LMDS.
   -1/2 d) Both (a) and (b) above.
   e) Both (b) and (c) above

2. Of MMDS and LMDS systems, the one most likely to need cellular-like frequency re-use planning is _____.
   a) LMDS
   b) MMDS

3. Air interface specifications for LMDS systems in the US are covered under the ___ standard.
   a) IEEE 802.16.1
   b) IEEE 802.16.2
   c) IEEE 802.16.3
   d) None of the above.

4. The following statements are true about MMDS and LMDS except statement _____.
   a) Both MMDS and LMDS systems can support 2-way digital communications.
   b) LMDS is capable of delivering more services than MMDS.
   c) Cost considerations currently make MMDS preferred over LMDS for some applications.
   d) MMDS is more suited to the needs of large commercial customers than LMDS.
   e) Both MMDS and LMDS systems require line-of-sight path with customer premises.

5. Communication satellites for fixed (non-mobile) applications are usually deployed in the _____ orbit.
   a) GEO
   b) MEO
   c) LEO
   d) Both (a) and (c) above.

6. In general, antennas for C-band satellite systems are larger than those for Ku- and Ka-band systems because _____.
   a) C-band was the first to be used for satellite communications.
   b) The Ku- and Ka-bands do not have as much traffic as the C-band.
   c) C-band is a lower frequency band than Ku- and Ka-bands.
   d) C-band is used only for high speed applications.
   e) All of the above.

7. The following statements are true about the geostationary orbit except statement ____.
   a) The geostationary orbit is at an altitude of about 36,000 km above the equator.
   b) At this altitude, communication signals incur a one-way propagation path delay of about 270 msec.
   c) Unlike satellites in LEO and MEO orbits, those in GEO orbit do not have to move.
   d) This orbit is used by many countries to deploy domestic and regional satellite systems.
   e) Satellites in this orbit circle the earth once a day.

8. GEO satellite systems cannot provide truly global coverage because _____.
   a) They use too little power to adequately service the tropical regions.
   b) Their altitude and orbit make it difficult to cover the polar regions adequately.
   c) Their satellites are too small to cover the whole earth.
   d) They use very old technology.

9. In comparing GEO-based satellite systems with those in LEO and MEO orbits, the following statements are true except statement _____ .
   a) LEO and MEO satellite systems use much lower transmit power.
   b) GEO satellite systems are better suited for global mobile communications.
   c) LEO and MEO systems can provide more complete coverage of the earth.
   d) LEO and MEO systems use radio spectrum more efficiently.
   e) GEO systems are preferred for fixed applications.

10. LEO and MEO satellite systems require more satellites to cover the earth because _____ .
   a) The satellites are too high above the earth.
   b) The satellites are too close to the earth.
   c) The satellites use regenerative transponders.
   d) The antennas used are much smaller than those used in GEO satellite systems.
   e) Both (a) and (d) above.

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Class Exercise #2 July 2, 2003

Student Name:_____

A). Answer True (T) or False (F):

T 1. In general, cellular mobile communication systems use much smaller base station coverage zones (cells) than pre-cellular systems.

F 2. Pre-cellular wireless systems did not re-use frequencies.

T 3. Ability to re-use frequencies in close proximity greatly enhances capacity of cellular mobile communication systems.

T 4. In cellular mobile communication systems, the group of nearby cells that uses up all of the system's traffic channels is called a cluster.

T 5. The MTSO (or MSC) is an essential element of any cellular mobile communication system.

T 6. First generation cellular mobile communication systems around the world used analog transmission format based on FM technology.

F 7. Second generation cellular mobile communication systems continue to use analog FM technology, just like their predecessors.

T 8. In the US, the FCC allocated new radio spectrum for the deployment of digital cellular service. Don't give away new

T 9. Dual-mode cellular telephones were introduced in many parts of the world to enable customers to be served via both analog and digital cellular networks.

F 10. The ITU-driven third generation (3G) wireless systems will be based on a single radio interface standard for all regions of the world.

B). Circle the one correct answer to each of the following statements:

1. In cellular mobile communication systems, an active call can be switched from one cell to another using the _____ feature.
   a) Cell splitting
   b) Call handoff
   c) Cell sectorization
   d) Frequency re-use
   e) Both (b) and (d) above

2. In a cellular system with a total of 140 traffic channels and using a cluster size of 7, each cell in the system can be allocated up to _____ traffic channels.
   a) 7
   b) 10
   c) 14
   d) 20
   e) 140

3. Wireless systems based on cellular design use low power base station transmitters so that _____.
   a) Frequencies can be re-used in close proximity to enhance system capacity
   b) System noise can be reduced
   c) Interference to other nearby wireless systems can be minimized
   d) Overall network infrastructure cost can be reduced
   e) All of the above

4. In cellular mobile communication systems, the _____ database is used to hold information on subscribers roaming from other cellular networks.
   a) Network Configuration
   b) HLR
   c) VLR
   d) Authentication Center
   e) None of the above

5. In cellular mobile communication systems, each of the following system entities gets involved in real-time call processing with the exception of the _____.
   a) Mobile station
   b) Base station
   c) Mobile Telephone Switching Office
   d) Network Control Center
   e) None of the above

6. The following statements are true about first and second generation cellular mobile systems except statement _____.
   a) In the US, first generation systems were all based on a single radio interface standard whereas multiple types of second generation systems are in use.
   b) In Europe, there were many types of incompatible first generation systems but only a single standard for second generation systems.

c) First generation systems based on US standards were never deployed in Europe, however US-based second generation systems can be found in many parts of Europe.

d) In Scandinavian countries, first generation systems were based on NMT standards (NMT 450 and NMT 900) whereas second generation systems are based on the GSM standard.

e) Both (a) and (c) above.

7. One of the primary reasons for the development of second generation cellular systems was to _____.

a) Make use of digital transmission technologies.

b) Allow easy integration of cellular systems with services offered in the PSTN.

c) Enable more efficient transport of data traffic.

d) Increase system capacity in major metropolitan areas.

e) All of the above.

8. All major second generation cellular systems of the world are based on TDMA technology except for the _____ system.

a) D-AMPS

b) cdmaOne

c) GSM

d) PDC

e) PHS

9. The predominant multiple access technology for IMT-2000 (3G) systems is expected to be _____.

a) FDMA

b) TDMA

c) CDMA

d) CSMA

10. One of the reasons that 3G systems will likely not operate in common frequency bands in all parts of the world is that _____.

a) The spectrum designated by the ITU for 3G systems is already being used for other services in some countries.

b) Some countries of the world do not wish to be bound by the ITU 3G spectrum recommendations.

c) Regional "politics" makes it impossible to align all countries within the designated bands.

d) Some countries prefer to use different frequency bands for 3G services.

e) Both (b) and (d) above.

8½/10

UC Berkeley Extension
X476.1 INTRODUCTION TO WIRELESS NETWORKS

Class Exercise #1 June 18, 2003

Student Name: Yacheng Shu

A). Answer True (T) or False (F):

T 1. In wireless communication systems, signals between the source and destination are propagated over the air/space using electromagnetic waves.

T 2. Wireless communication systems have been deployed in various sub-bands within the radio, microwave, and infrared frequency bands.

F 3. Most public and major private wireless communication systems use ~~infrared~~ RF technology for over-the-air communications.

T 4. The RF band includes all frequencies up to 300 GHz.

T 5. The VHF, UHF and SHF bands are where most major public wireless communication systems currently operate.

F 6. The three primary communication modes in wireless systems are simplex, near-duplex and full-duplex.

T (-½) 7. Full-duplex wireless communication is only possible using Frequency Division Duplexing.

F 8. Communication signals can be transmitted in one of three formats: analog, digital or asynchronous.

F 9. Time Division Duplexing works best with analog transmission formats.

F (-½) 10. In wireless communication systems, the ~~forward~~ control channel is used for transmitting messages to wireless devices whereas the reverse ~~control~~ traffic channel is used by wireless devices to send messages to the network.

B). Circle the one correct answer to each of the following statements:

1. Wireless communication systems use either RF or _____ technology for the wireless link between the transmitter and receiver.
   a) microwave
   b) infrared
   c) satellite
   d) coaxial cables
   e) None of the above

2. The following are all examples of wireless communication systems, with the exception of _____ .
   a) TV remote control systems
   b) Wireless LANs
   c) Fiber optic communication systems
   d) Cellular telephone systems
   e) Satellite communication systems

3. In these kinds of wireless communication systems, the user's physical location can vary but the user station must not be mobile while communicating.
   a) Fixed wireless systems
   b) Portable communication systems
   c) Mobile communication systems
   d) Transportable communication systems
   e) Nomadic communication systems

4. In general, the higher the frequency of an electromagnetic wave the _____ the range that can be achieved with a given transmit power level.
   a) longer
   b) shorter

5. In mobile communication systems using paired channels, the mobile station is normally assigned the lower frequency as its transmit channel so that _____.
   a) The mobile station's range can be limited
   b) The mobile station antenna can be kept small
   c) The mobile station power requirements can be minimized to permit the design of lightweight user devices
   d) All of the above

6. In this mode of communication, transmission can occur in both directions but not simultaneously.
   a) Half-duplex communication mode
   b) Full-duplex communication mode
   c) Simplex communication mode
   d) None of the above

7. To transmit an analog signal using digital format, the signal must first be _____ .
   a) Modulated

b) Decoded
c) Digitized
d) Both (b) and (c) above

8. In this traffic channel sharing technique, a user is assigned a dedicated traffic channel for entire duration of a call.
   a) CSMA
   b) CDMA
   c) TDMA
   d) FDMA

9. Of FDMA, TDMA and CDMA, the most spectrum-efficient multiple access scheme is___.
   a) FDMA
   b) TDMA
   c) CDMA

10. The most popular traffic channel sharing technique in wireless local area networks is____
   a) TDMA
   b) CSMA/CA
   c) CDMA
   d) CSMA/CD

Session 1:

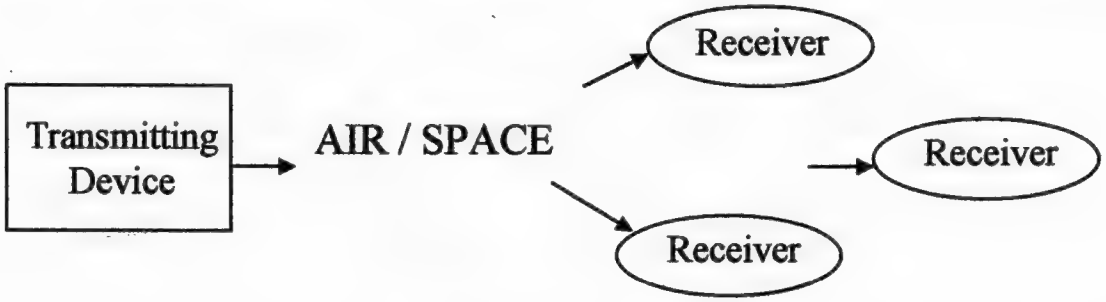
Introduction to Wireless Communications

OUTLINE

- Wireless Communication Defined
- Classification of Wireless Communication Systems
- Major Wireless System Application Categories
- Electromagnetic Waves and Wireless Communications
- General Characteristics of Electromagnetic Waves
- Radio Spectrum for Wireless Communications
- Designations and Main Uses of Wireless Communication Bands

Wireless Communication Defined

- *Wireless communication* implies an untethered connection between the source of the communication (transmitting end) and the intended recipient (receiving end)
  - The transmitting and receiving devices may be fixed or capable of moving



  - Connection between the transmitter and receiver is accomplished through unguided medium (air/space) using radio waves (RF) or infrared (IR) technology
    - RF technology is the option most commonly used in public and major private wireless communication systems
    - Infrared transmission is found in some short-range wireless system applications

Wireless Communication Defined

- Examples of wireless communication systems and products:
  - Remote control systems for home entertainment systems (TVs, stereo systems, VCRs), garage door sensors, etc
  - Cordless telephone systems, walkie-talkies
  - Radio paging systems (pagers)
  - Wireless messaging systems
  - Wireless Local Area Networks (WLANs)
  - Mobile radio dispatch systems
  - Cellular telephone and PCS systems
  - Microwave radio systems
  - Satellite communication systems
  - Broadband fixed wireless distribution systems (LMDS, MMDS)

Classification of Wireless Communication Systems

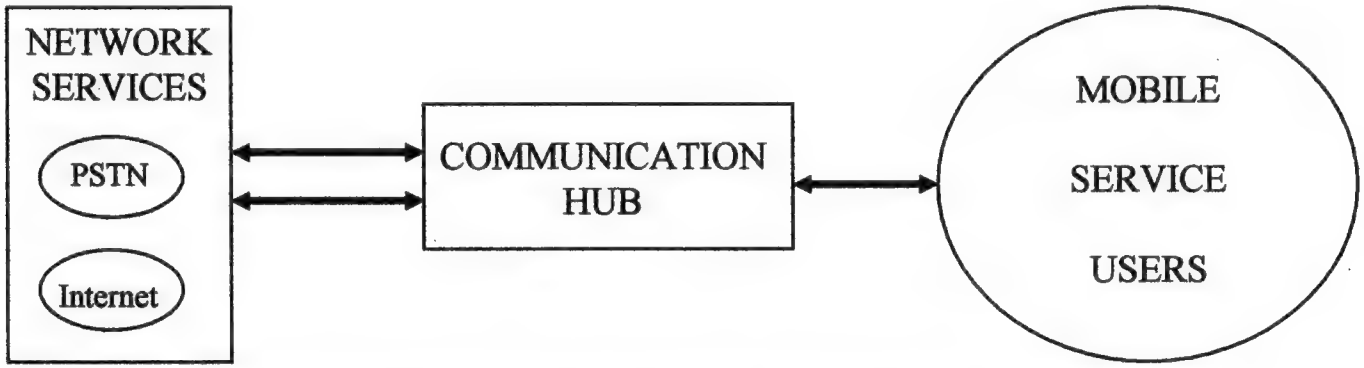
- Wireless communication systems fall under the following two broad classifications:
  - Terrestrial systems:
    - Where all communication network infrastructure is resident on the ground
  - Satellite communication systems:
    - Where a satellite up in the sky is part of the communication network infrastructure
    - Some terrestrial-based systems use information from specialized satellite systems (e.g. GPS system) for timing, ranging, etc.
- Systems can be designed for one or more of the following four categories of wireless system applications:
  1. Mobile communications
  2. Portable communications
  3. Fixed wireless communications
  4. Transportable communications

Major Wireless System Application Categories

1. Mobile Communication Systems:

These are wireless communication systems in which one or both ends of the communication link are capable of being in motion at high speeds (e.g. vehicular speeds)

- Typically, this class of wireless systems consists of one or more fixed communication hubs providing access to network services to mobile users



- Cellular telephone systems are the most popular example of mobile communication systems
- Mobile radio systems, paging/messaging systems are other examples

Major Wireless System Application Categories

2. Portable Communication Systems:

- Portable communications may involve motion up to normal pedestrian speeds
  - Residential cordless telephones, walkie-talkies, are good examples
  - In the UK, second generation cordless telephone systems (CT2) were introduced in 1989 to allow use of cordless telephones outside the home
    - Idea was to be able to use the same cordless phone handset while at home and away in the vicinity of a CT2 access point (*telepoint*)
      - High infrastructure cost, range limitations and lack of broad customer adoption resulted in these systems never really taking off
  - Europe's enhancement to CT2 produced the *Digital European Cordless Telephone* (DECT) system, proposed by Ericsson (Sweden) in 1992
    - DECT is used primarily to support mobility within an office PBX environment
  - In the US, the *Personal Access Communication System* (PACS) was proposed in 1992, but it never took off
  - Japan's *Personal Handyphone System* (PHS) is by far the most successful outdoor portable/semi-mobile communication system

Major Wireless System Application Categories

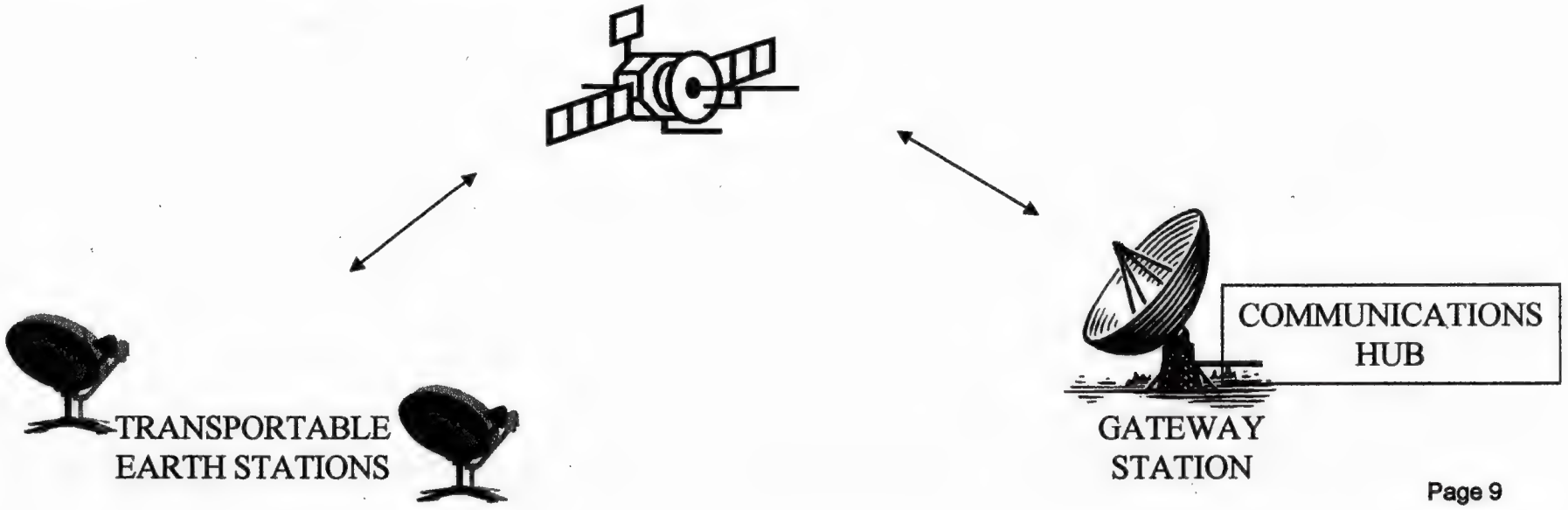
3. Fixed Wireless Systems:

- Fixed wireless systems are a type of wireless communication systems in which neither end is capable of being mobile
  - These systems are well suited for broadband applications as they can support communication at very high data rates
    - Some implementations of fixed wireless systems can support data rates comparable to those achievable on wired facilities
  - Point-to-point microwave systems, fixed satellite communication systems, BETRS, LMDS and MMDS broadband wireless systems are good examples
    - BETRS: Basic Exchange Telecommunication Radio Service
    - LMDS: Local Multipoint Distribution Service
    - MMDS: Multi-channel Multipoint Distribution Service
      - MMDS is also referred to as wireless cable service

Major Wireless System Application Categories

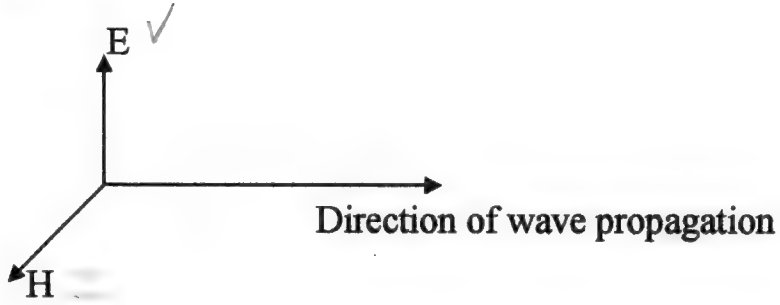
4. Transportable Communication Systems:

- Transportable communication systems are essentially fixed wireless systems in which the user's physical location can vary
  - Transportable cellular telephones were fairly common in the early days of cellular service
  - Most common uses of transportable communications nowadays are in TV remote broadcast feeds via satellite



Electromagnetic Waves in Wireless Communications

- Communication signals in wireless systems are propagated over the air using electromagnetic waves
- An electromagnetic wave consists of orthogonal electric (E) and magnetic (H) fields



  - The electric field is a manifestation of potential energy (V), and the magnetic field is a manifestation of kinetic energy (I)
- Since power is a function of V and I, an electromagnetic wave traveling through space or any other transmission medium therefore transfers power

General Characteristics of Electromagnetic Waves

- An electromagnetic wave propagating through a medium does so at a fixed speed known as the *phase velocity* (v_p)

$$v_p = c / \sqrt{\varepsilon_r}$$

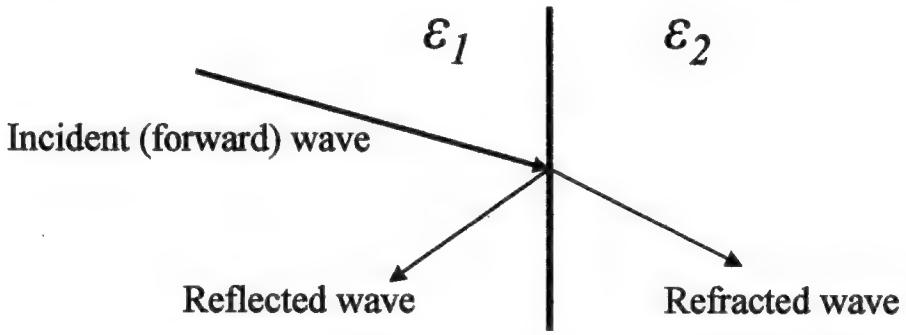
where c is the speed of light = 3 x 10^8 m/sec,

and ε_r is the relative dielectric constant of the medium of propagation

- In vacuum, $\varepsilon_r = 1$, and the speed of electromagnetic wave propagation = c (the speed of light)
  - All other media have relative dielectric constants > 1
    - i.e. electromagnetic waves travel the fastest when going through vacuum
- Air has an ε_r very close to 1, and the speed of electromagnetic wave propagation in air is also approximated as c
  - ε_r of dry air = 1.00068 (which is approximately = 1)

General Characteristics of Electromagnetic Waves

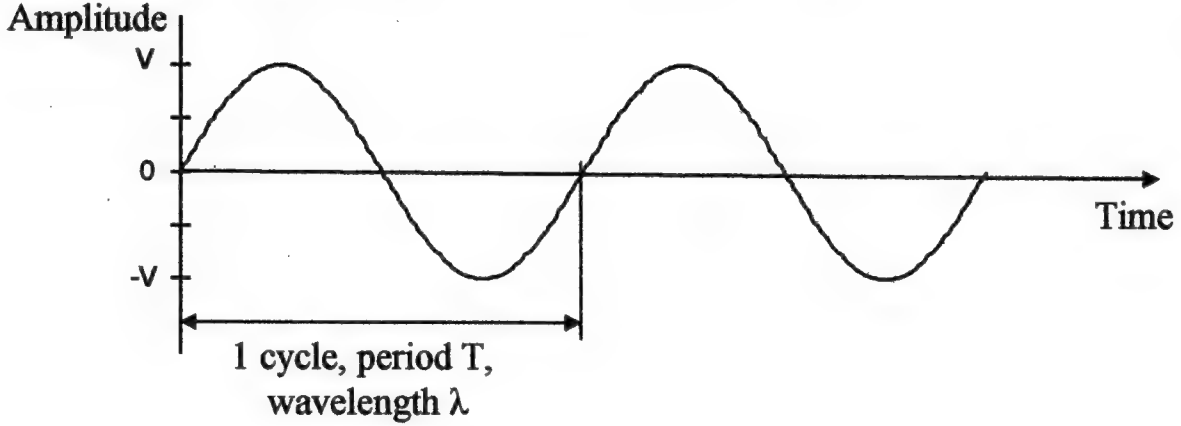
- When an electromagnetic wave hits a boundary of a medium with a different dielectric constant, reflection occurs



  - Dielectric constant is also referred to as *permittivity*: it is a measure of a medium's ability to support an electric field
    - The sum of the energies of the reflected and refracted waves equals the energy of the incident wave
    - The magnitude of the refracted wave depends on the medium's dielectric constant
  - A medium's ability to support a magnetic field is referred to as *permeability*

General Characteristics of Electromagnetic Waves

- Electromagnetic signals behave differently depending on their *frequency*
  - The frequency *(f)* of an electromagnetic signal is the rate (in cycles per second, i.e. Hz) at which the signal pattern repeats

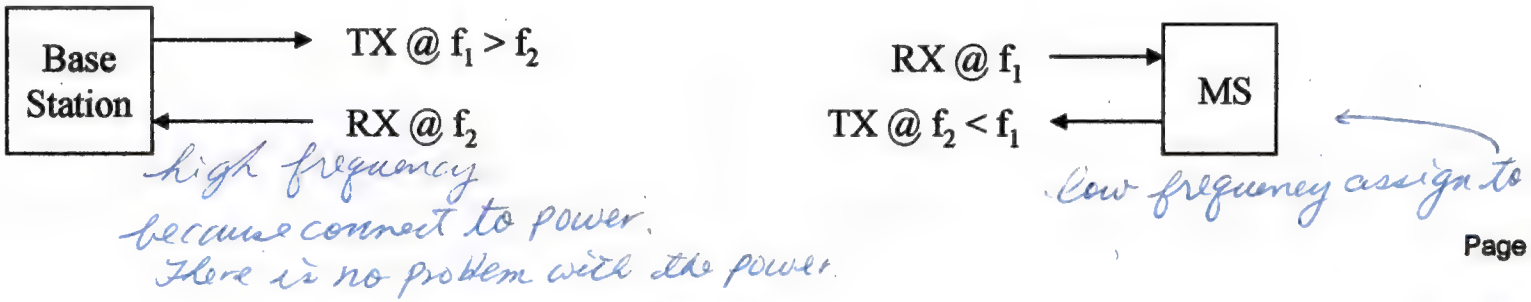


1 Hz = 1 cycle/sec
1 kHz = 10^3 Hz
1 MHz = 10^6 Hz
1 GHz = 10^9 Hz
1 THz = 10^{12} Hz

  - The amount of time it takes for one cycle to complete is referred to as the ***period*** *(T)* of the signal (Note that: $T = 1/f$)
  - The distance occupied by one cycle is called the ***wavelength*** *(λ)* of the signal
    - In free space, $\lambda = c / f$; where c is the speed of light

General Characteristics of Electromagnetic Waves

- In general, waves at lower frequencies penetrate through objects better than those at higher frequencies and can achieve longer range
  - The higher the frequency of operation the higher the transmit power required to achieve a desired range
    - In most wireless communication applications, lower frequencies are therefore preferred
  - Newer wireless systems are often deployed in higher frequency bands due to unavailability of sufficient spectrum in the lower bands
  - In mobile communication applications using paired channels, the mobile station is normally assigned the lower frequency as its transmit channel
    - This minimizes power at the MS and supports design of lightweight handsets

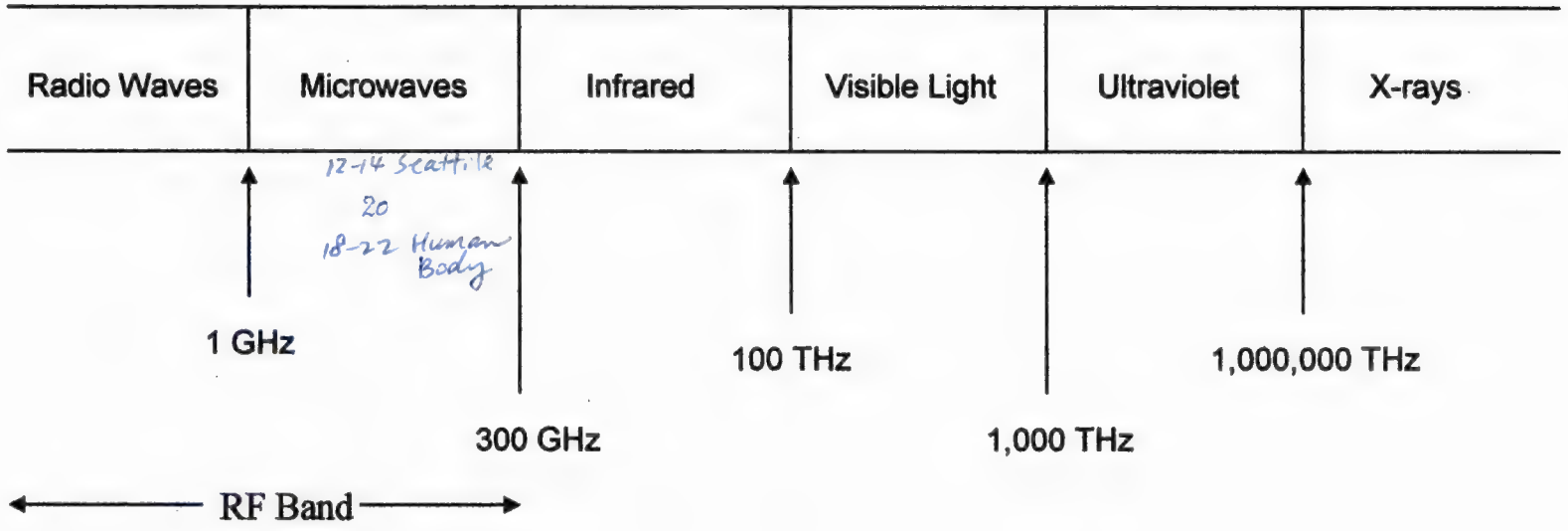

Base Station
TX @ $f_1 > f_2$
RX @ f_2
RX @ f_1
TX @ $f_2 < f_1$
MS
high frequency because connect to power. There is no problem with the power
low frequency assign to

General Characteristics of Electromagnetic Waves

- The size of antenna required to efficiently radiate electromagnetic energy into the air/space is inversely proportional to the frequency of the signal
  - This makes possible, for example, the use of very small satellite dishes in the Ku (12/14 GHz) and Ka (20/30 GHz) bands
  - But it is also a source of considerable challenges in the engineering of high frequency circuits

Radio Spectrum for Wireless Communications

The Electromagnetic Spectrum:



- Wireless communication systems have been deployed in various sub-bands within the radio, microwave, and infrared frequency bands
- The radio and microwave bands comprise the *radio frequency (RF)* band
- The sub-band 30 GHz to 300 GHz is referred to as the *millimeter wave* band
  - Wavelengths in this sub-band are less than a centimeter long (i.e. < 10 mm)

$\lambda = c/f$

$= \frac{3 \times 10^8}{f}$

$\lambda_{30GHz} = \frac{3 \times 10^8}{30 \times 10^9} = 10mm$ $\lambda_{300} =$ 1mm

Designations and Main Uses of Wireless Communication Bands

Frequency Range	Name	Main Uses
< 300 Hz	Extremely Low (**ELF**)	Submarine / power lines
300 Hz – 3 kHz	Intra Low (**ILF**)	Voice band
3 kHz – 30 kHz	Very Low (**VLF**)	Audio band
30 kHz – 300 kHz	Low (**LF**)	Long range systems
300 kHz – 3 MHz	Medium (**MF**)	Broadcast radio (AM)
3 MHz – 30 MHz	High (**HF**)	Shortwave radio
30 MHz – 300 MHz	Very High (**VHF**)	Broadcast radio (FM)/ paging systems / mobile radio / VHF TV
300 MHz – 3 GHz	Ultra High (**UHF**)	Mobile telephony / microwave systems / UHF TV
3 GHz – 30 GHz	Super High (**SHF**)	Microwave / satellite systems / broadband wireless systems
30 GHz – 300 GHz	Extremely High (**EHF**)	Microwave / satellite systems
> 300 GHz	Tremendously High (**THF**)	Infrared systems / Experimental

- Operational cellular/PCS communication systems are in the UHF band
  - Most pre-cellular mobile communication systems operated in the VHF band
- Commercial satellite communication systems are primarily in the SHF band

Bandwidth (Hz)

Shannon's capacity law: $C = B \log(1 + S/N)$

capacity (or speed) (bits/sec)

logorithm (very large # in the reasonable

$\log_{10} A = x \Rightarrow 10^x = A$ $\quad x=2 \Rightarrow 10^2 = A = 100$

instead of dealing with 100, you deal with 2.

need more powers

Spectrum: 700 MHz.

2GHz (3GHz) no more higher than (3G)

Session 2:

Wireless Communication Terminologies and Definitions

OUTLINE

- Wireless Communication Modes
- Signals and Transmission Formats
- Wireless System Components
- Radio Channel Types
- Control Channel Access Methods
- Traffic Channel Sharing (Multiple Access) Techniques
- Network Traffic Switching Schemes

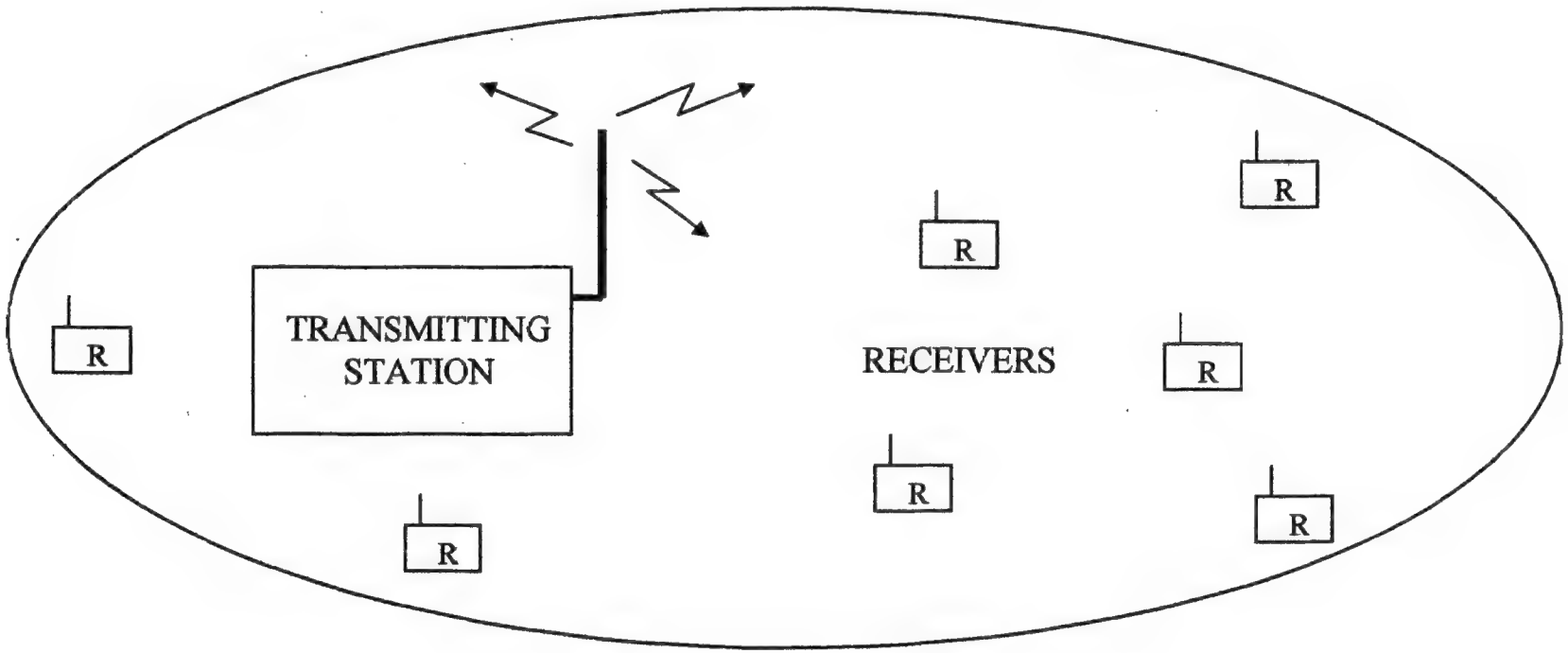
Wireless Communication Modes

- Three primary communication modes:

    1. Simplex communication mode
    2. Half-duplex communication mode
    3. Full-duplex communication

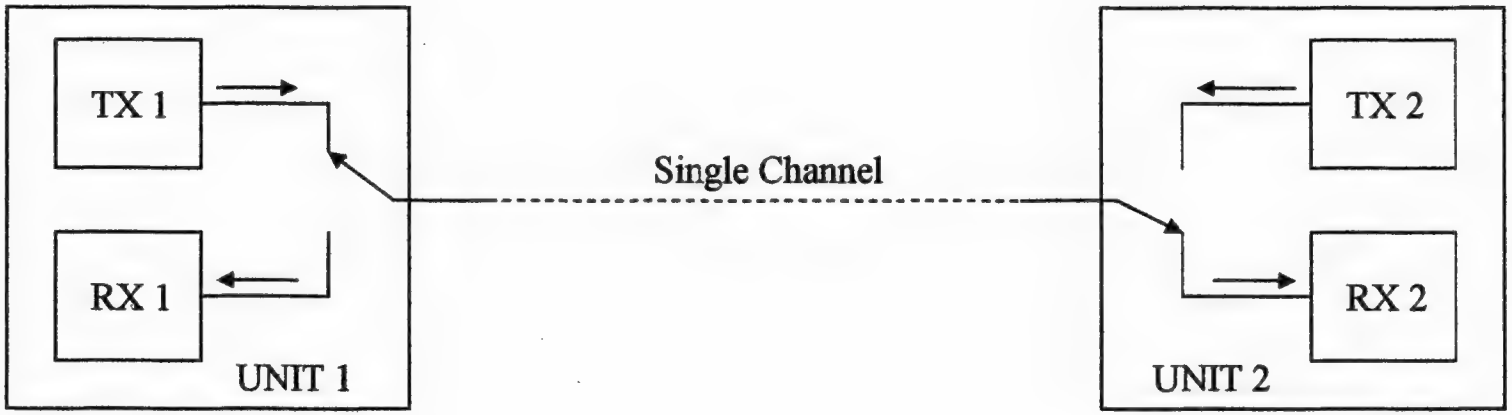
Communication Modes: (1) Simplex Communication

- **Simplex** communication systems are one-way communication systems
  - Transmission occurs in only one direction
  - One-way paging systems, standard public AM/FM radio and TV systems are examples



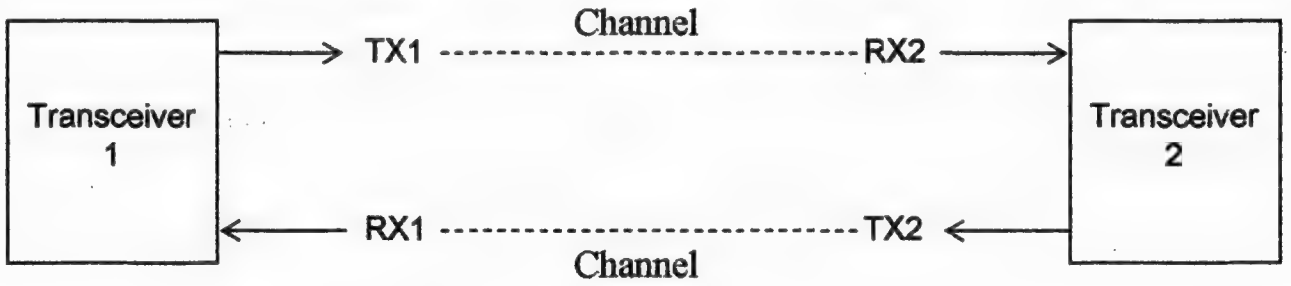
Communication Modes: (2) Half-duplex Communication

2. **Half-Duplex** communication systems allow two-way communications but not simultaneously
   - Single communication channel shared by both ends, so only one end can transmit at a time
   - Manual TX/RX mode selection; push-to-talk technology
   - Walkie-talkies, mobile radio dispatch systems are examples



Communication Modes: (3) Full-duplex Communication

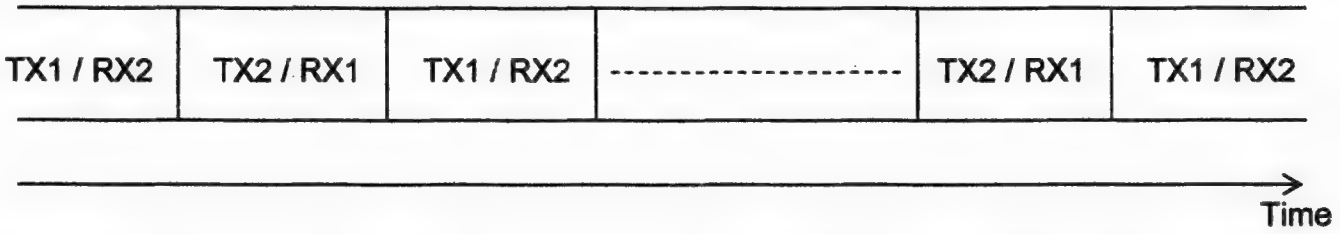
3. **Full-Duplex** systems allow simultaneous transmission and reception
   - Typically, transmit channel is separate from receive channel
     - Frequency Division Duplexing **(FDD)**
     - Each channel operates in a simplex mode



   - Current generations of cellular telephone systems are good examples of FDD full-duplex systems

Communication Modes: (3) Full-duplex Communication (cont'd)

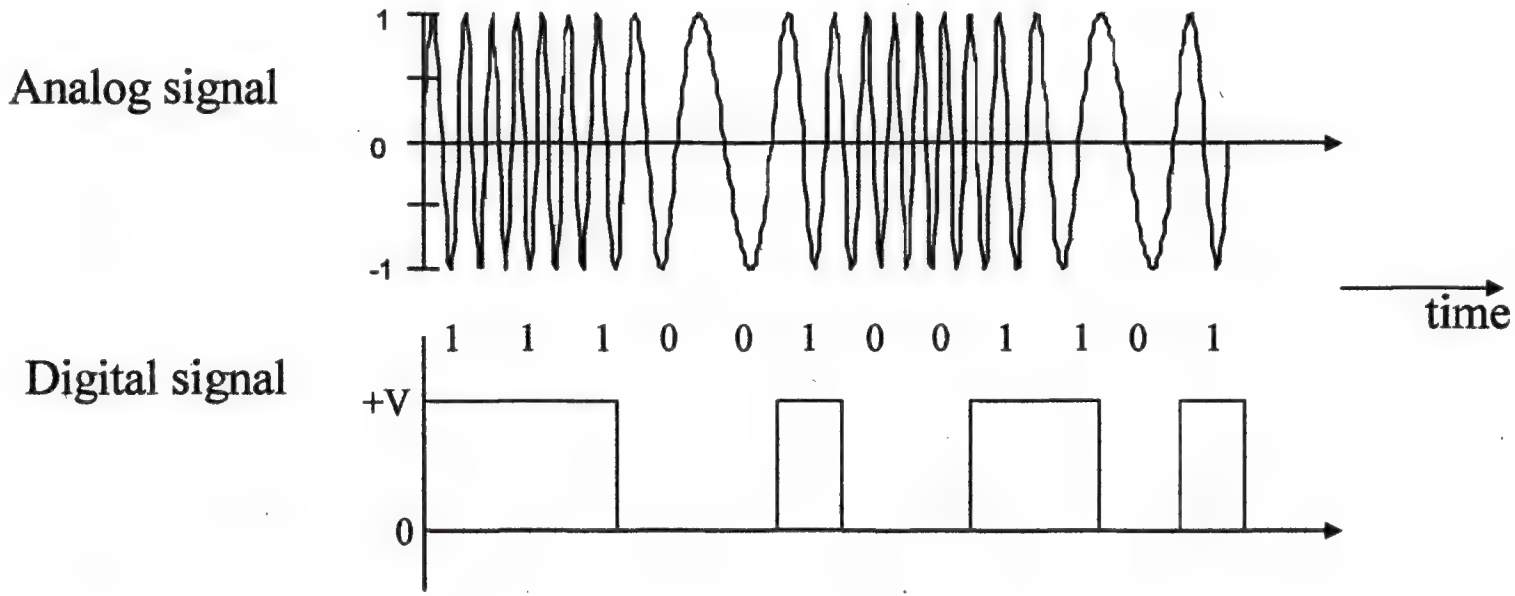
- Full-duplex communications also possible using Time Division Duplexing **(TDD)**
  - A single radio channel is shared for transmissions from both ends
  - Fast time slot switching gives the appearance of full-duplex operation to the user
    - Essentially half-duplex system with fast, automatic TX/RX switching



  - TDD is very sensitive to timing, and only possible with digital transmission formats
  - It is one of the technology options for third generation (3G) cellular mobile telecommunication systems

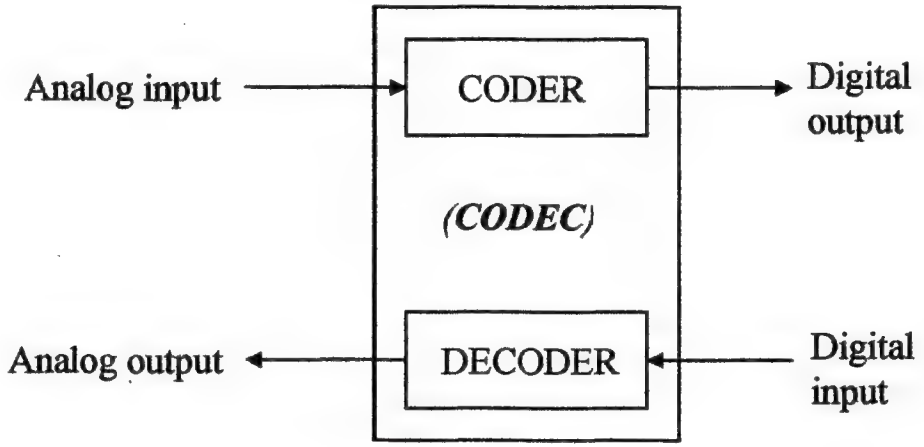
Signals and Transmission Formats

- Communication signals can be transmitted in one of two formats: *analog* or *digital*
- An *analog signal* is a continuously varying electromagnetic wave, whereas a *digital signal* is a sequence of voltage pulses



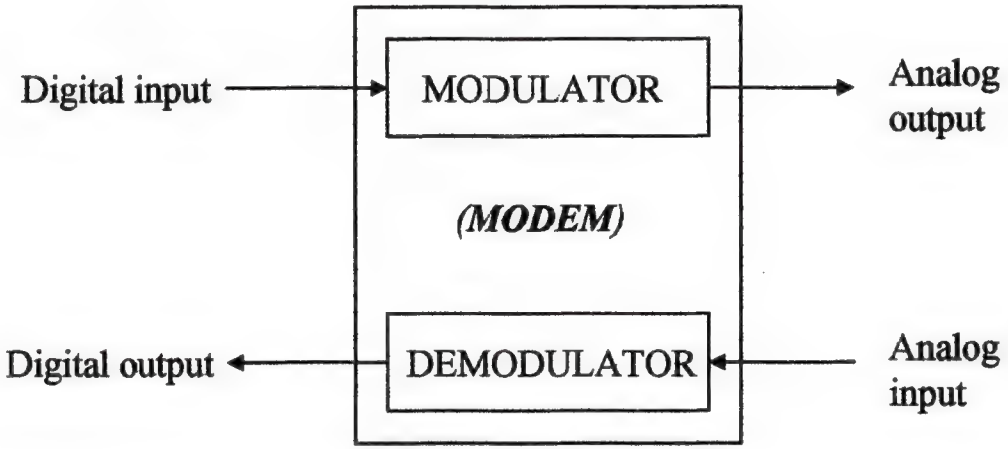
Signals and Transmission Formats (cont'd)

- To transmit an analog signal using digital format, the signal must first be converted into digital format (process called *digitization*)
  - Devices that perform the digitization process are referred to as *coders*
  - At the receiving end, *decoders* are used to reconstruct the analog signal from the received digital stream
  - The coder and decoder functions are most commonly packaged together in one device called the *codec*



Signals and Transmission Formats (cont'd)

- To transmit a digital stream of data using analog format, the signal must be translated into an analog signal
  - A *modulator* is used to convert a digital bit stream into an analog signal suitable for transmission over a transmission medium
  - At the receiving end, a *demodulator* is used to reproduce the digital stream from the received analog signal
  - The modulator and demodulator functions are most commonly packaged together in a device called the *modem*



Wireless System Components

- Wireless Devices / Stations
  - Comprising all types of devices used to provide user interface to network services
    - Examples: Pagers and other messaging devices, cellular telephones (mobile stations), wireless multimedia devices
  - May be voice-only, data-only, or multimedia capable
  - Devices communicate with the network via the wireless technology specified for the system
- Base Station
  - Radio network component used to provide the wireless interface to user devices
    - It is essentially the wireless transceiver and associated antenna system
  - Communicates with user devices using pre-defined signaling protocol and channel sharing format
  - A typical wide-area wireless network has many base stations
    - Each base station covers an area (range) dictated by system design

Wireless System Components (cont'd)

- Cell Site
  - This represents the physical location where base stations are housed
  - Typically also contains cell site-to-switching center and/or network control center communication equipment, alarm monitoring equipment, an antenna tower, and stand-by power supply system
  - Cell site equipment is typically installed inside a building or a shed
- Network Switching Center
  - Used in networks which require a switching function (e.g. cellular telephone networks)
  - Switching centers permit interconnection of wireless users within the same network, and may provide access to other networks (e.g. the PSTN or the Internet)
- Network Control Center
  - This represents the master control center for the entire wireless network
  - Typically includes a network management center, system administration computers, customer databases

Radio Channel Types

- Two types of radio channels typically encountered in a wireless system: *control channels* and *traffic channels*
- Control channels are used for control and system administration messaging between the network and wireless devices
  - The network uses the *forward control channel* to broadcast messages to wireless devices (e.g. incoming call notifications, acknowledgements, etc.)
    - Wireless devices in idle state tune to and monitor the forward control channel
  - The *reverse control channel* is used by wireless devices to send messages to the network (e.g. system registrations, service requests, etc.)
- Traffic channels are used to carry user traffic (voice, data, etc.)
  - Wireless devices are assigned to traffic channels by the network on a demand and availability basis
    - Traffic channel requests that cannot be accommodated result in blocked calls
  - Wireless devices relinquish traffic channel occupancy upon call completion and return to the control channel

Control Channel Access Methods

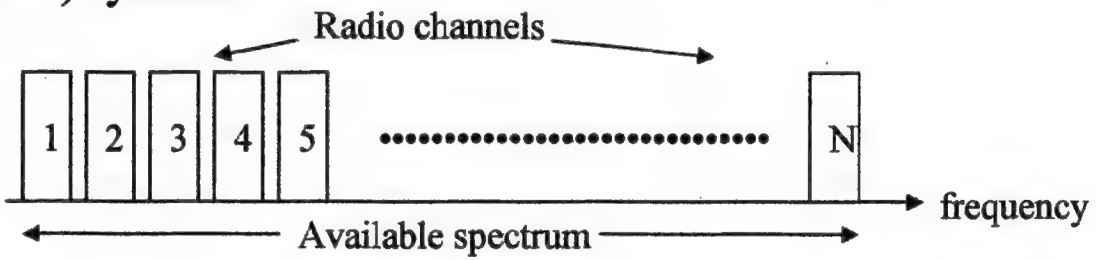
- Wireless devices generally access the shared reverse control channel in a random (uncontrolled) or semi-controlled fashion
- The most popular random access scheme in use is *Aloha*
  - Under Aloha scheme, wireless devices transmit on the shared channel anytime they have messages to send to the network
    - If a transmitted message is not responded to within specified time, collision is assumed, and the device retransmits after a random delay period
  - The maximum throughput (success rate) of an Aloha system is about 18%
- Some systems control shared channel accesses using the *slotted Aloha* scheme
  - Under the slotted Aloha control scheme, wireless devices transmit on the shared channel only during time windows specified by the network
    - The network indicates on the forward control channel when transmissions from wireless devices are allowed
  - Slotted Aloha can achieve twice the throughput of pure Aloha ($\approx 37\%$)

Traffic Channel Sharing (Multiple Access) Techniques

- Wireless communication systems are generally deployed on limited amount of radio spectrum
  - Radio spectrum for wireless systems is scarce and has become very expensive to acquire in recent years
  - Efficient methods of managing traffic channel usage are necessary to accommodate the highest amount of traffic
- Four traffic channel sharing techniques are in use in modern-day wireless communication systems:
  1) Frequency Division Multiple Access (FDMA)
  2) Time Division Multiple Access (TDMA)
  3) Code Division Multiple Access (CDMA)
  4) Carrier Sense Multiple Access (CSMA)

Traffic Channel Sharing Techniques: (1) FDMA

- FDMA is the oldest spectrum sharing/management technique
- In FDMA, the available radio spectrum is subdivided into as many narrowband radio channels as possible
  - The narrow traffic channels are assigned to users upon demand
    - One user per traffic channel, dedicated for entire duration of a call
    - FDMA systems are sometimes referred to as Single Channel Per Carrier (SCPC) systems

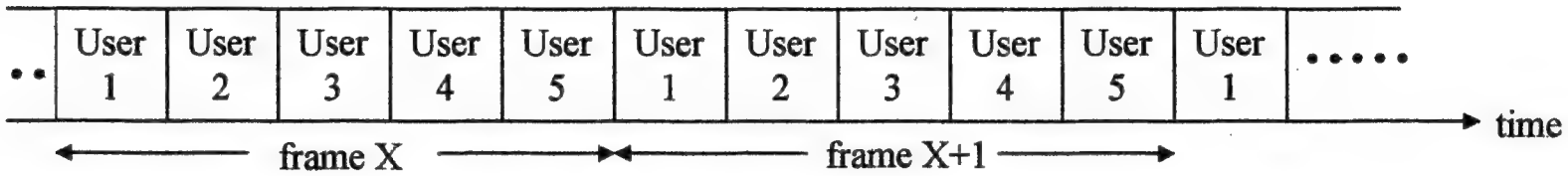


  - Efficient channel management software is used to ensure fast call set-up and tear-down for optimum spectrum utilization
- FDMA is nowadays used primarily in wireless systems which employ analog transmission format

Traffic Channel Sharing Techniques: (2) TDMA

- In TDMA, each radio channel is subdivided logically in short time slots which are used to carry user traffic
  - The number of time slots per channel (and hence number of users that can be accommodated simultaneously on the channel) depends on system design and intended applications

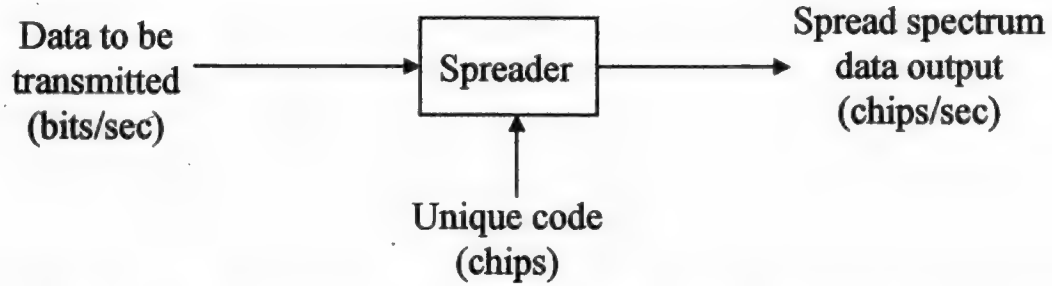
Example TDMA Channel:



  - Each user is assigned a time slot upon demand, for duration of the call
    - Also possible for a user to be assigned multiple time slots on each frame
  - TDMA requires strict time synchronization and works only with digital transmission
  - TDMA is more spectrum efficient than FDMA

Traffic Channel Sharing Techniques: (3) CDMA

- In CDMA systems, many users share a common radio channel at the same time
  - Each user is assigned a unique code to use in processing its packets for transmission
    - Spread spectrum technology is used for this stage of processing



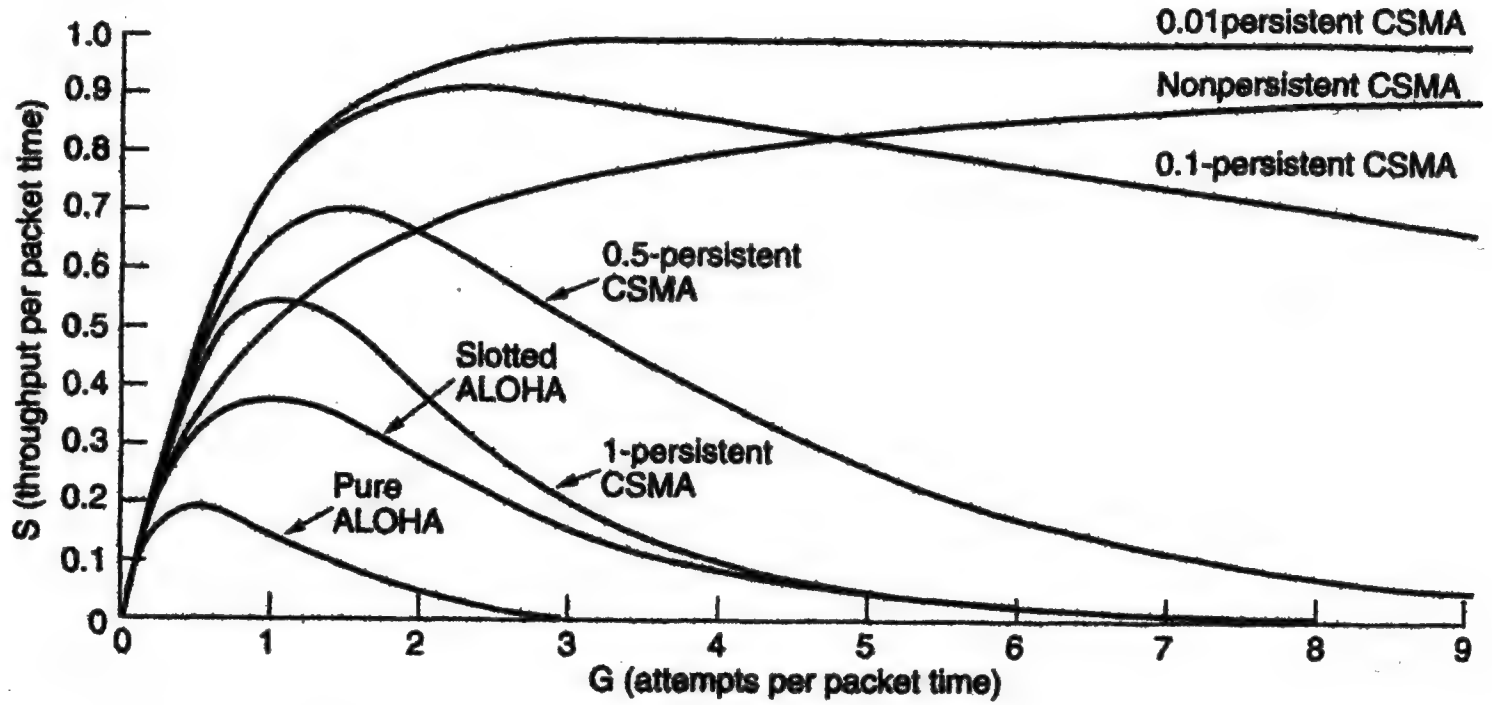
  - The codes used are nearly orthogonal and have good autocorrelation and cross-correlation properties
    - Results in many users's transmissions to co-exist on the same radio channel at the same time without interfering with each other
    - Also permits use of same channel frequency in each cell in the network
  - CDMA is the most spectrum efficient of all known multiple access schemes
    - It is the main technique in next generation (3G) cellular networks

Traffic Channel Sharing Techniques: (4) CSMA

- CSMA is a random access protocol primarily used in local area networks
- It is a scheme which improves upon the Aloha access methods
  - If a device has data to send, it first listens (senses) on the shared channel to see if anyone else is transmitting at the moment
    - This clearly improves performance over Aloha since it minimizes collisions
- Various versions of CSMA protocols have been proposed:
  1) *1-Persistent CSMA:* If channel is busy, the device continues to monitor it until it becomes idle, then seizes it and begins to transmit its data
  2) *p-Persistent CSMA:* When the channel becomes idle, the device transmits with a probability *p* (i.e. device may transmit or defer to the next idle slot)
     - Achieves higher throughput than 1-persistent CSMA, but has longer delays
  3) *Non-persistent CSMA:* If channel is busy, device does not keep monitoring it continuously, rather it waits a random period of time then senses it again
     - Also achieves high throughput, but introduces long delays

Traffic Channel Sharing Techniques: (4) CSMA (cont'd)

Comparison of channel throughput for various random access protocols



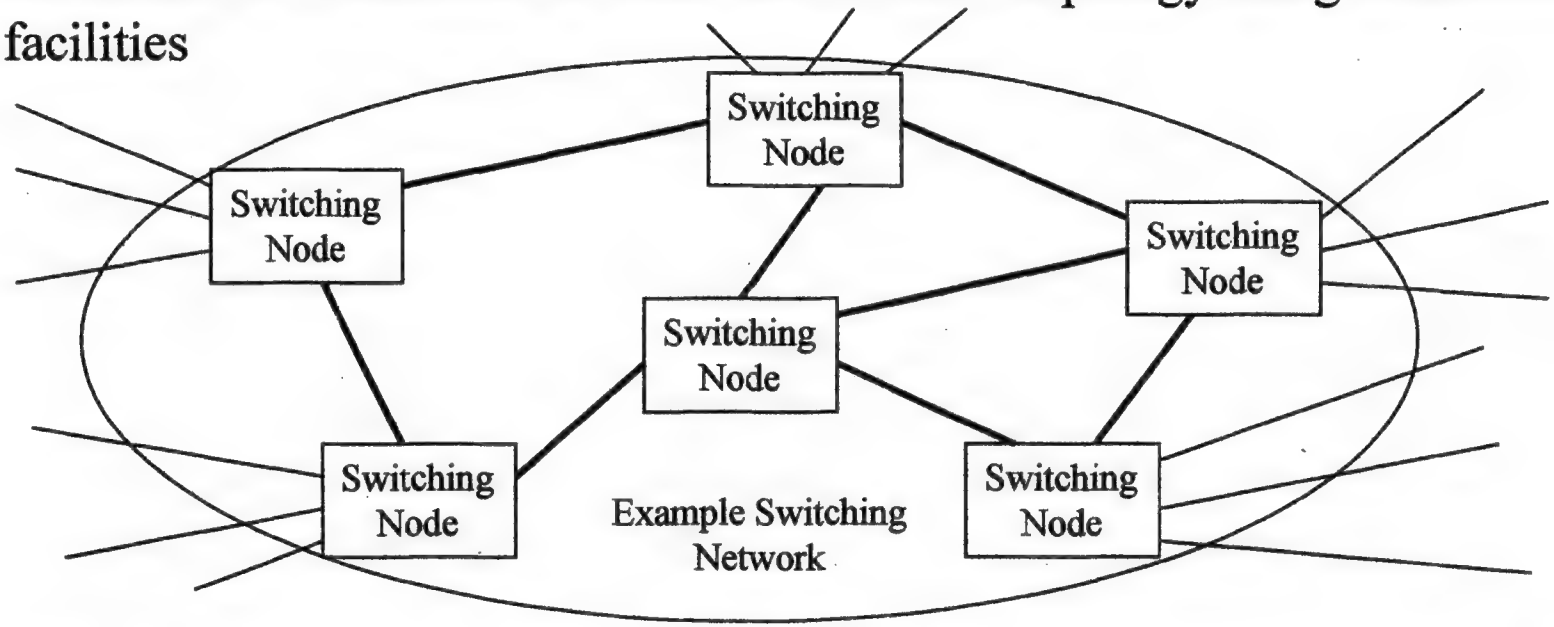
(Source: Andrew S. Tanenbaum's "*Computer Networks*", 3rd Edition, Prentice Hall PTR)

Traffic Channel Sharing Techniques: (4) CSMA (cont'd)

4. *CSMA with Collision Detection:* In CSMA/CD, the transmitting device continuously monitors the channel for collisions and stops transmitting when it detects one
   - Quickly terminating damaged frames saves time and increases channel capacity
   - CSMA/CD is the most popular protocol in wired local area networks
     - Not practical in wireless networks due to inability to monitor outgoing transmissions
5. *CSMA with Collision Avoidance:* In CSMA/CA, if the channel is busy, the device waits a random time interval (backoff time) before sensing the channel again
   - If the channel is still busy, the device waits another backoff time interval which is less than the first; process continues until the channel clears
     - The device then sends a *Ready to Send* (RTS) packet to the destination with indication of the length of the transmission; destination acknowledges with a CTS message
   - CSMA/CA avoids collisions primarily because the likelihood of any two devices randomly selecting the same backoff time interval is slim
     - Use of RTS / CTS messages with transmission length value (*virtual carrier sense*) also assists with collision avoidance
   - CSMA/CA is the most popular protocol in wireless LANs

Network Traffic Switching Schemes

- For reasons of economics and facility utilization efficiency, landline communication networks are built using distributed switching nodes
  - The nodes are connected to each other in some topology using transmission facilities



  - User traffic enters the network through the serving switching node and exits at the switching node serving the called party
  - Intermediate switching nodes are not concerned with the content of the data; rather their purpose is to quickly move the data towards the destination

Network Traffic Switching Schemes (cont'd)

- Data is routed through the communication network using one of two switching techniques: *circuit switching* or *packet switching*
- In circuit switching, a dedicated communication path is established between the source and destination, for entire duration of the call
  - The path is a connected sequence of dedicated links (channels) between switching nodes
  - Circuit switching is the dominant technology for voice networks (e.g. PSTN)
    - It is rather inefficient, but best option for real-time communications where delay is not tolerated
- In packet switching, facilities are not reserved between the source and destination
  - Rather, at each node the packet header is examined to determine destination, then the node determines the next leg of the route and sends out the packet
    - Consecutive packets in a message may take different paths to the destination
    - Packet Assemblers/Disassemblers (PADs) are used to re-order the received packets
  - Packet switching is very efficient for handling data traffic and is used in major data networks such as the Internet
    - Ongoing VoIP research promises to overcome delay issues for voice applications

Session 3:

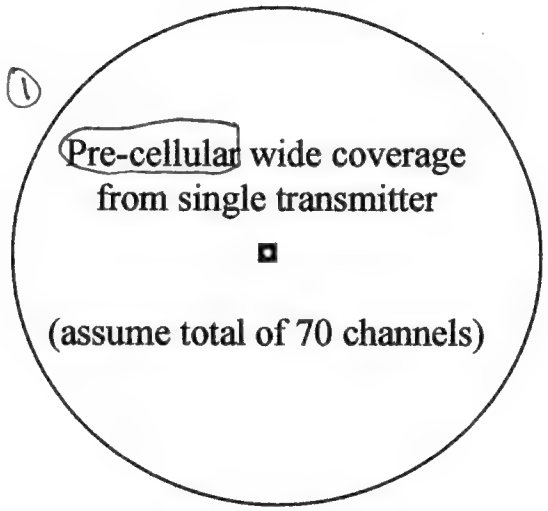
Introduction to Cellular Mobile Communication Systems

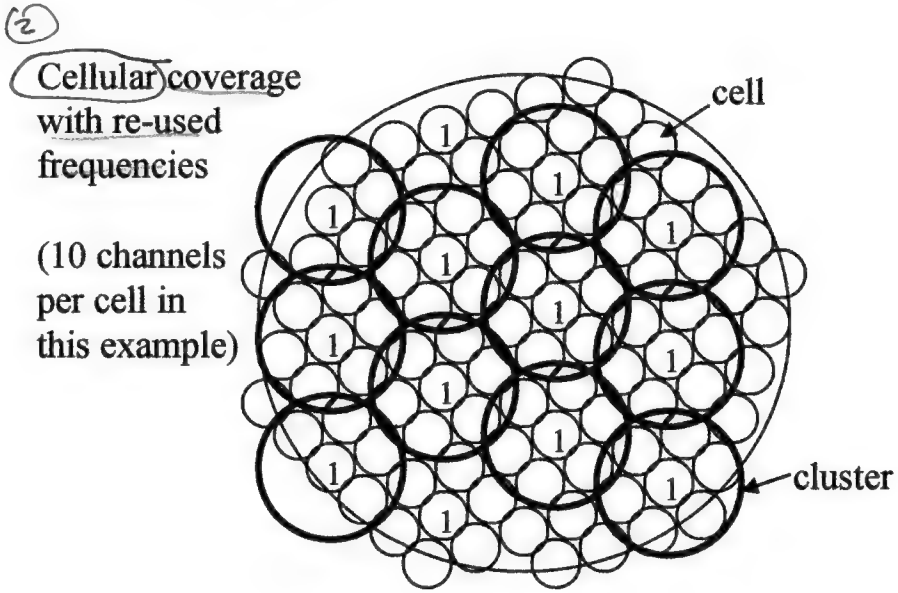
OUTLINE

- Introduction to Cellular Mobile Technology
- General Architecture of Cellular Mobile Networks
- Core Elements of a Cellular System
  - Mobile Station
  - Base Station
  - Mobile Telephone Switching Office
  - Network Control Center
  - Network Interconnection Facilities
- Sample Mobile Station Call Processing
- Sample MTSO Call Processing

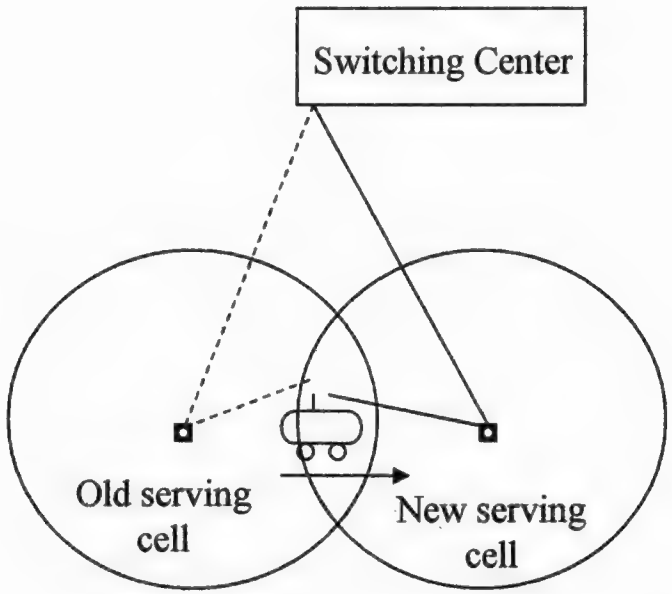
Introduction to Cellular Mobile Technology

- When first deployed in the early 1980's, networks based on cellular technology represented breakthroughs in a number of areas:
  1. Frequency Re-use in Close Proximity:
     - ① – Pre-cellular systems re-used frequencies at very large geographical distances
       - Use of large coverage areas from high powered hill-top antennas meant that only a small number of customers could be accommodated in any area
     - ② – Cellular mobile technology greatly enhances system capacity by using many low power transmitters and re-using the frequencies in not-too-distant cells





2. Call Handoff
   - Use of small cells increases the chance of active calls extending beyond the coverage of a single transmitter
     - Call handoff feature allows such calls to be automatically switched from one cell to another seamlessly, without any user interaction



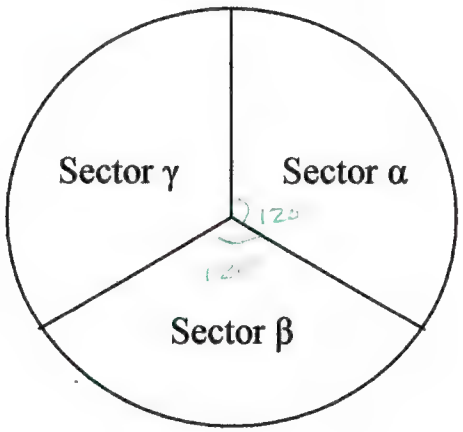
     - Sophisticated algorithms are used to ensure handoff to the correct cell

Introduction to Cellular Mobile Technology

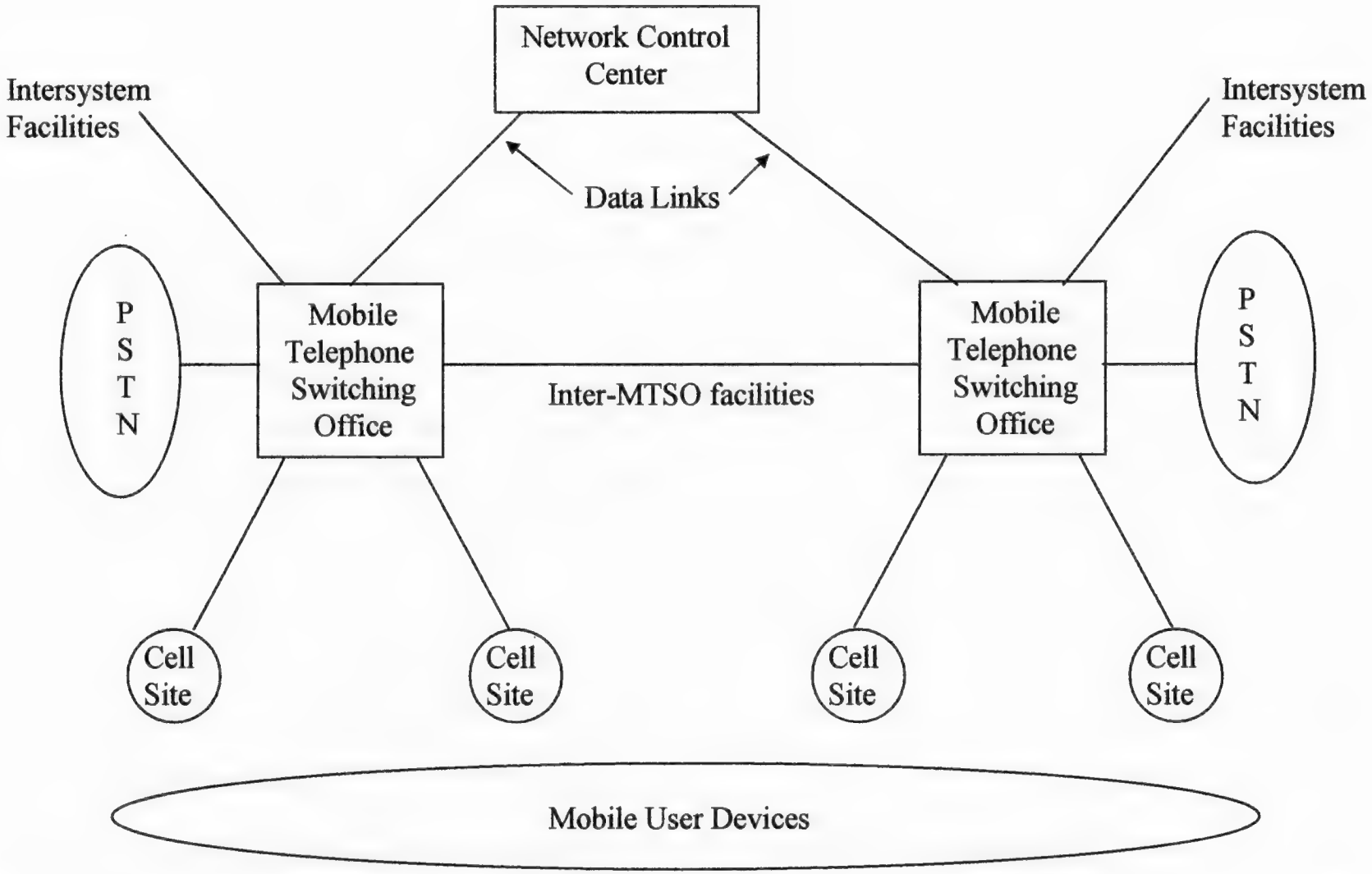
3. Cell Splitting to Increase Area Capacity
   - When capacity demand in any service area exceeds available capacity, the cells in the area are subdivided further to create many more smaller cells (microcells)
     - This creates more channel clusters (and hence increases capacity) in the area

4. Cell Sectorization to Manage Noise
   - When noise level in a cell becomes too high (due to volume of users and traffic), directional antennas can be used to effectively sectorize the cell into smaller service areas
     - Using three 120° antennas, the noise level in each sector is reduced by 2/3
       - This improves call quality without affecting system capacity noticeably

more capacity, make the cell small



General Architecture of Cellular Mobile Networks



Core Elements of a Cellular System

- Mobile Station (MS)
- Base Station (BS)
  - Referred to as Radio Base Station (RBS) in Europe
- Mobile Telephone Switching Office (MTSO)
  - Referred to as Mobile Switching Centre (MSC) in Europe
- Network Control Center (NCC)
  - Also known as Network Operations Center (NOC)
- Network Interconnection Facilities

Mobile Station (MS)

- A Mobile Station provides the user interface to cellular network services
  - it communicates with the Base Station via the air using radio (RF) signals

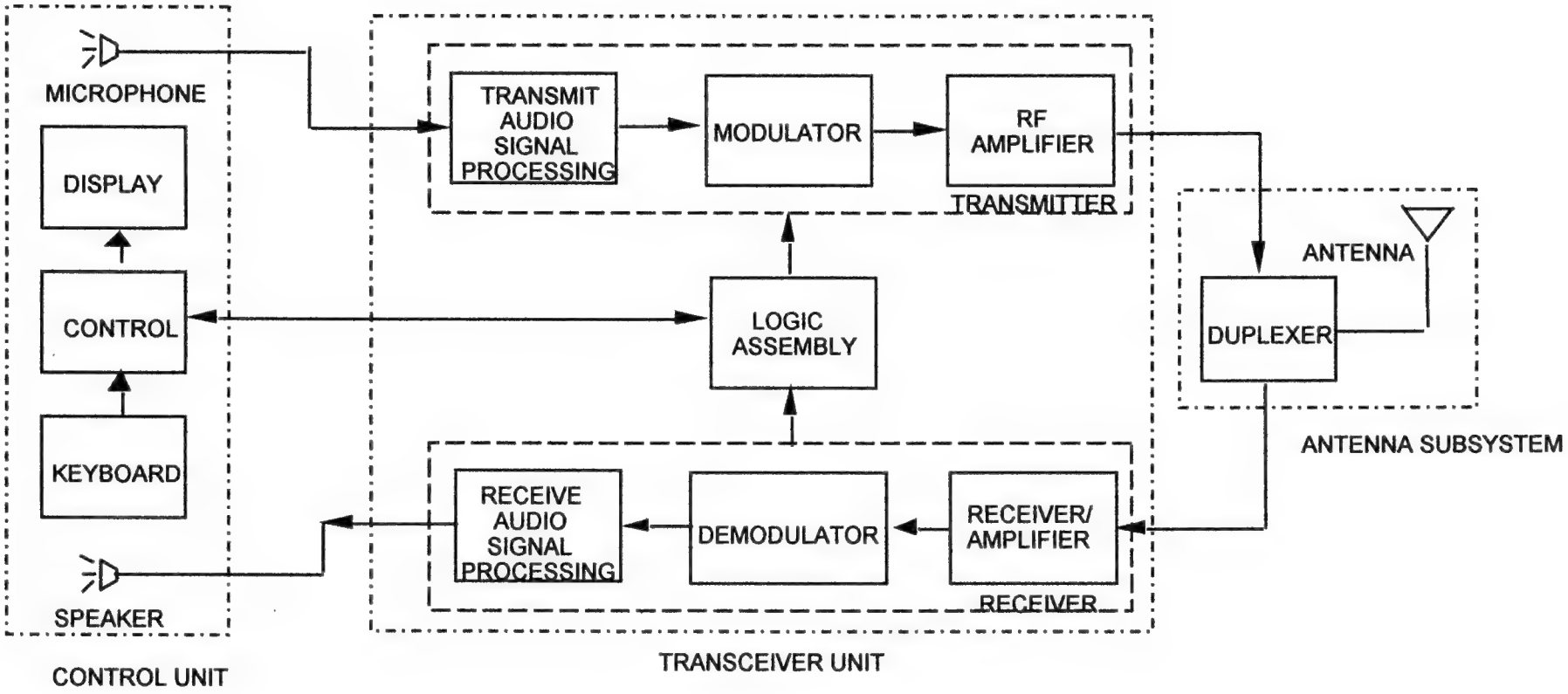
- Mobile Stations transmit at the different power levels, depending on station type and technology standard:

Portables:	0.1 - 0.6 W
Mobile:	1 - 3 W
Transportable:	1 - 3 W

- A Mobile Station consists of the following subsystems:
  - **Transceiver Unit**
  - **Control Unit**
  - **Antenna Subsystem**

Mobile Station (MS)

- A basic block diagram of a Mobile Station is illustrated below:



Mobile Station Subsystems

- **Transceiver Unit**
  - comprises the transmitter and receiver signal processing chains
    - converts outgoing baseband input signal to RF for transmission to the BS, and incoming RF signal from the BS into baseband output for the user.

- **Control Unit**
  - provides the primary man-machine interface for the MS user
    - contains a microphone, speaker, display, keypad and control electronics

- **Antenna Subsystem**
  - radiates outgoing RF energy from MS transmitter chain
  - focuses incoming RF energy for receiver chain processing

** Note that in portable units, all subsystems are contained in one package

Base Station (BS)

- Base Stations provide the radio communication interface between Mobile Stations and the fixed cellular network
  - they are located at cell sites, which are typically in the center or on the edge of cells
- A Base Station consists of:

  Transceivers

  Control Subsystems

  Antenna Assembly

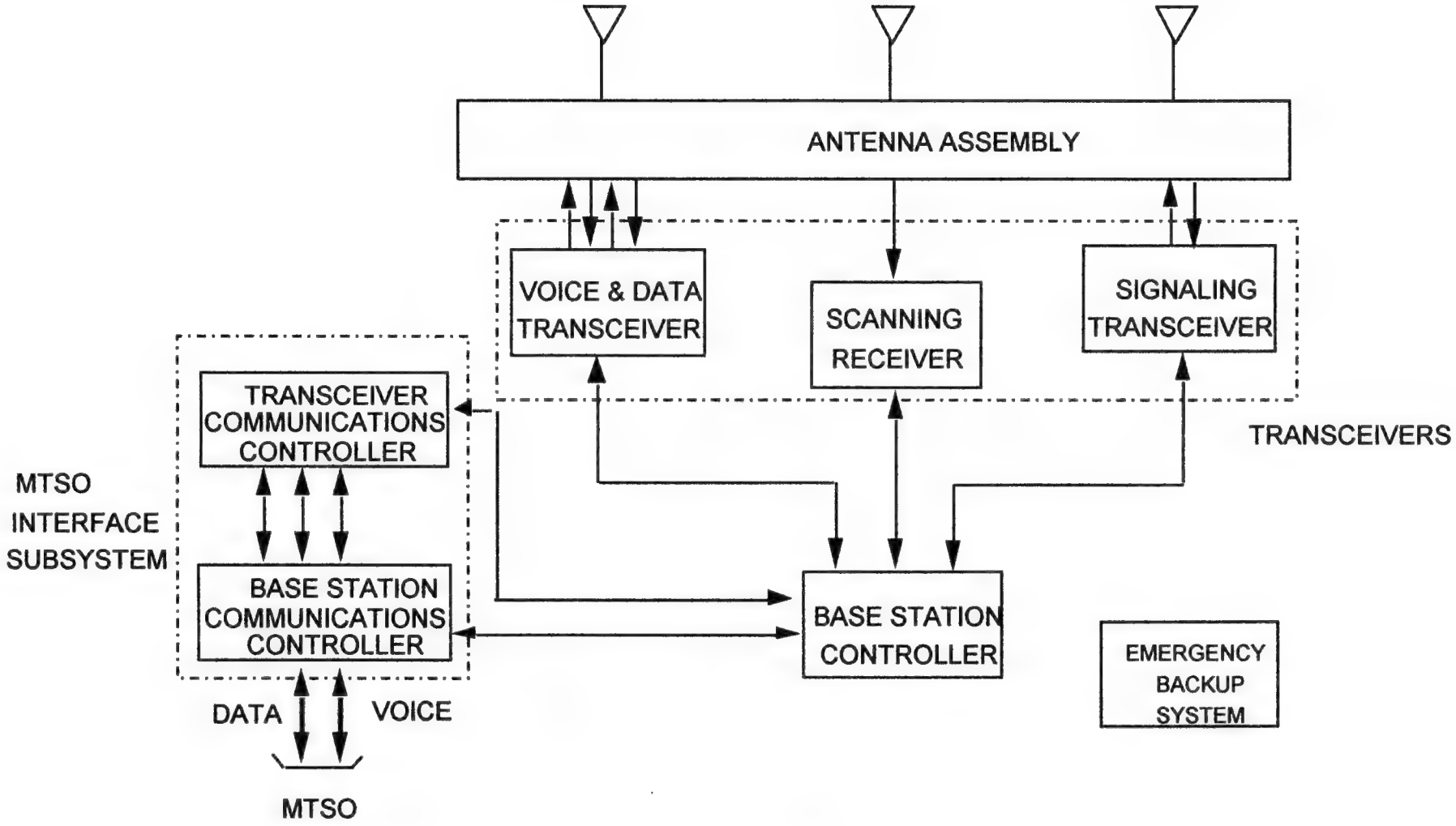
  MTSO Interface Subsystem

- Typical Base Station parameters:

Transmit power	5 to 45 W
Antenna elevation	6 to 100 meters.
Coverage area	100 m to 16 km radius.

Base Station

- A basic block diagram of a Base Station is illustrated below:

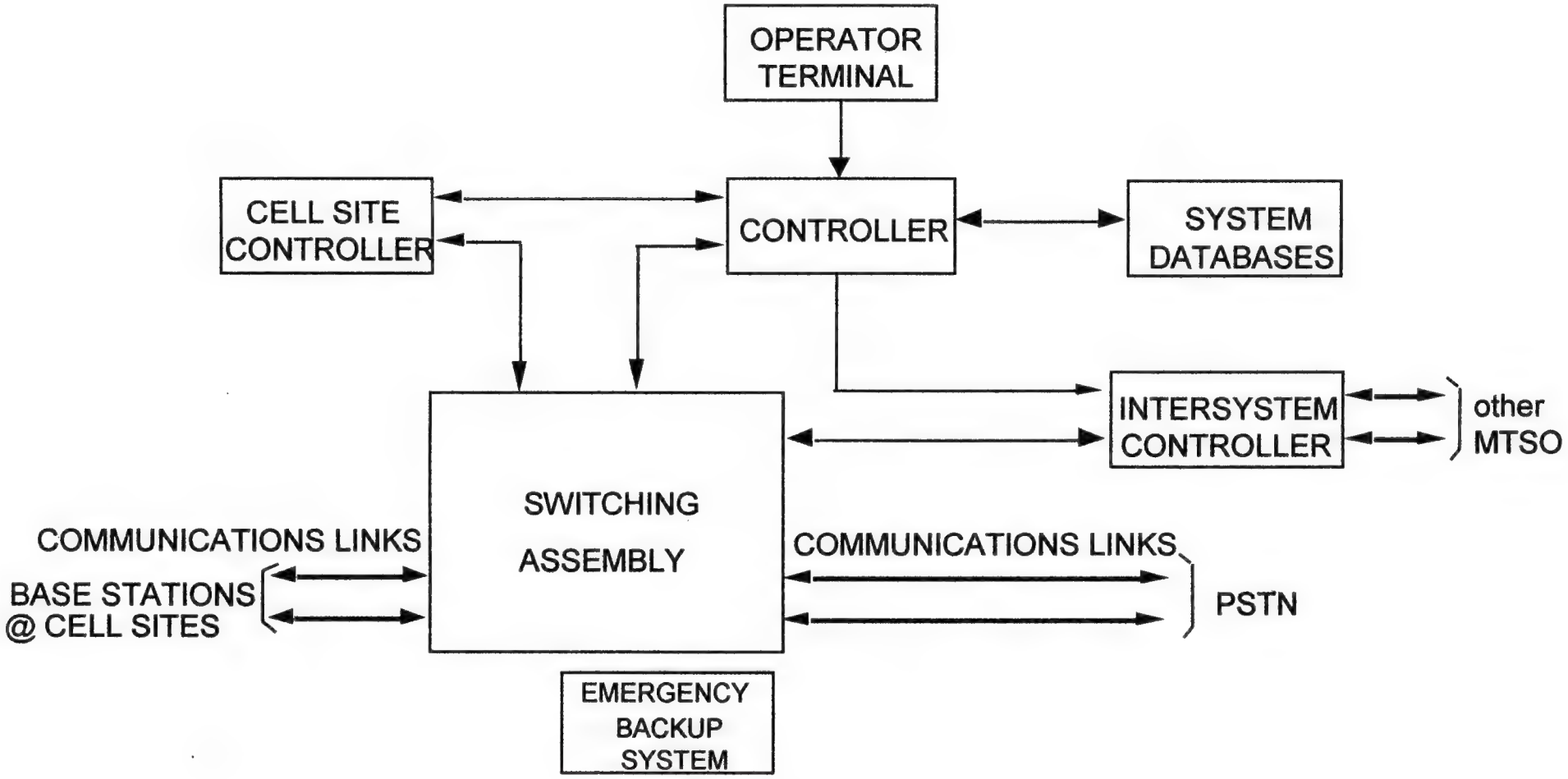


Mobile Telephone Switching Office (MTSO)

- MTSOs serve as the central control and switching nodes in cellular networks
  - They provide switched access to the PSTN, and between Base Stations
  - They manage customer database information
  - They provide interface to billing computers
  - They manage call processing activities of all Base Stations connected to them
    - Some networks offload this function to a Base Station Controller (BSC)
- The number of cells connected to (controlled by) an MTSO varies according to equipment type and capacity requirements
  - a typical MTSO can handle 150,000 subscribers, 5,000 cellular calls at a time, and about 500,000 busy hour call attempts (BHCA)
    - outboard HLRs which can handle about one million subscriber records are also available
- Large cellular networks use multiple interconnected MTSOs to permit intra-network inter-MTSO call routing

Mobile Telephone Switching Office (MTSO)

- A functional block diagram of an MTSO is illustrated below:



MTSO Entities

- **Switching Assembly**
  - Interfaces with Base Stations (cell sites) on one side, and with the PSTN on the other
    - under control of a call processing controller, can connect (switch) any Base Station channel to any PSTN line or another Base Station channel
    - contains all necessary interface hardware and software for signaling with the PSTN during processing of incoming and outgoing calls
  - Switch equipment typically same as standard Class 5 PSTN switches (e.g. #5ESS, AXE 1000, DMX 10, etc)

- **Controllers**
  - Consist of processors, memory, software and hardware that enable the MTSO to perform its functions
  - Control switching and non-switching functions
    - call processing, system monitoring, diagnostics, billing record-keeping, system administration, intersystem operations, etc.
  - Involved in real-time processing of calls

MTSO Entities

- **System Databases**

  Examples:

  - **Customer Database (HLR)**
    - Containing customer-specific information such as subscriber identity, contact numbers, MIN/ESN, billing address, features subscribed to, etc.
    - Interfaces with the **Authentication Center (AC)**
  - **Visitor Database (VLR)**
    - containing data on visiting (roaming) cellular subscribers
  - **Network Configuration Database**
  - **Call Records and Billing Data**
  - **Network Performance Statistics**

- **Operator Terminals**
  - includes computer terminals and other pieces of equipment used to access the various databases

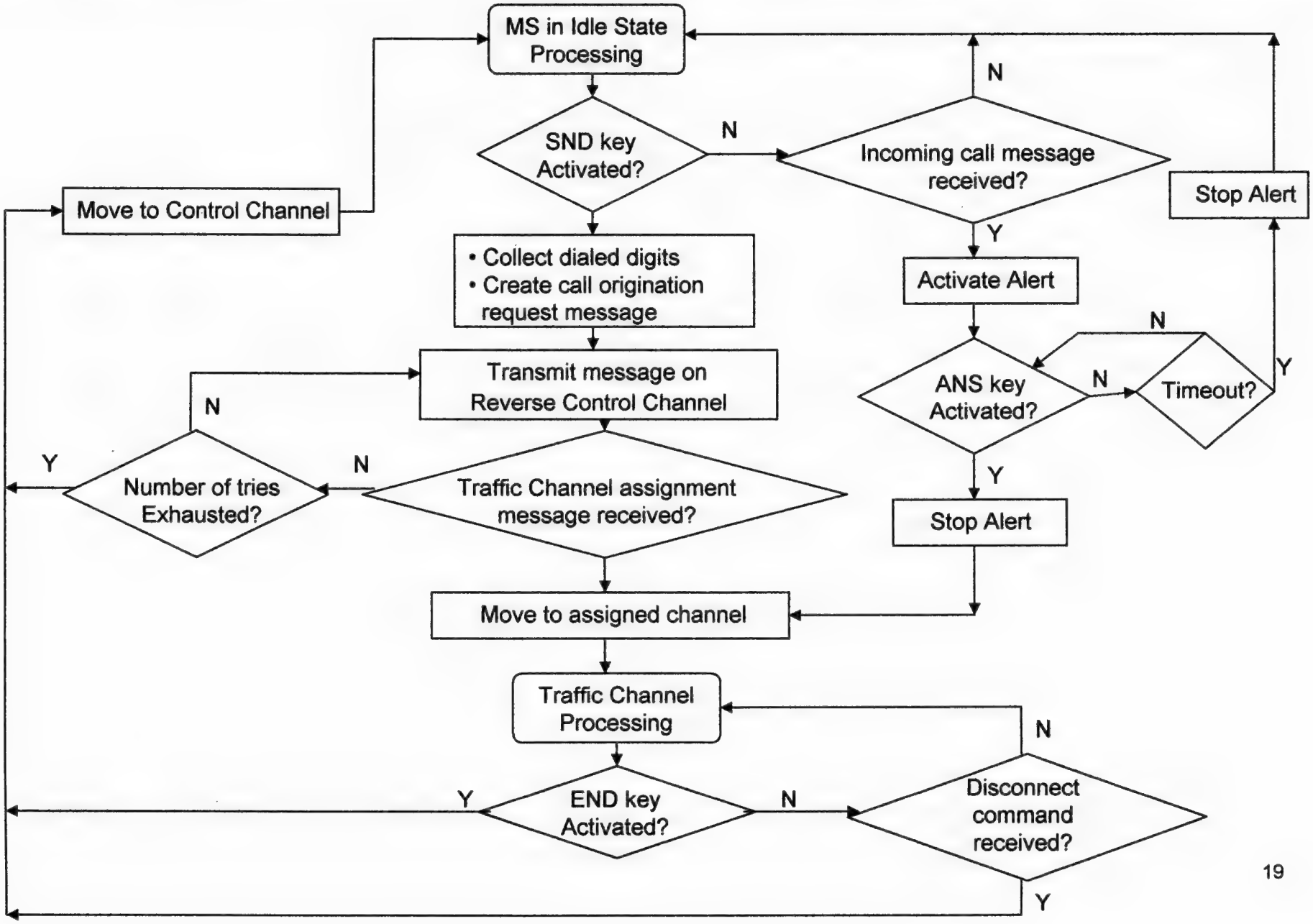
Network Control Center (NCC)

- The NCC serves as the overall master control center for the system
  - It houses computers and associated interface peripherals for monitoring the health of the network, including interconnecting facilities
  - Includes software for performing diagnostic routines on remote network elements
  - Center is typically manned on a 24/7 basis
- NCCs perform background network surveillance functions and are not involved in the real-time processing of calls
  - Uses Network Management System (NMS) software
- Most cellular networks use one redundant NCC, however some large geographically expansive networks use regional NCCs
  - Such NCCs would typically be interconnected to provide redundancy and to permit more cost-effective network monitoring during off-peak hours
    - Network monitoring can be remoted to one NCC when appropriate

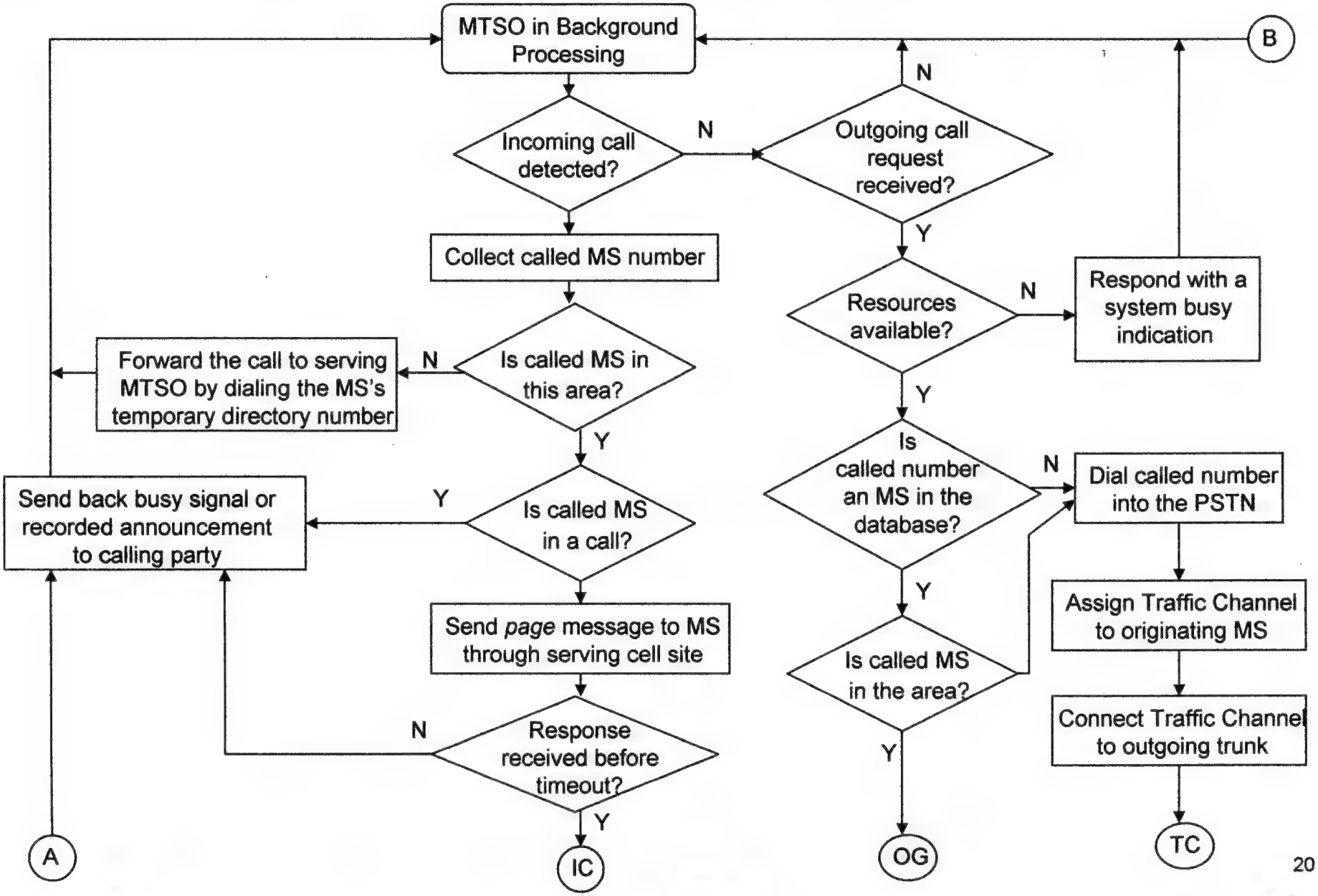
Network Interconnection Facilities

- **Cell Site to MTSO Interface**
  - Digital transport typically used (T1 or E1 based)
  - May be wire-based or use microwave transmission
  - Standardized interfaces (A/A*bis*) to permit multi-vendor base station environment
    - In practice, this capability is very rarely used
- **MTSO to PSTN Interface**
  - Standardized interface (A_i), compatible with the public telephone network
  - Various types of interconnection arrangements currently possible
    - Interconnection Agreements negotiated with landline telephone companies
- **Intersystem (MTSO to MTSO) Interface**
  - Standardized interface (E) to allow inter-network communications for roamer processing
    - X.25 and SS 7 signaling are currently the supported formats
    - ATM and IP schemes expected in 3G systems

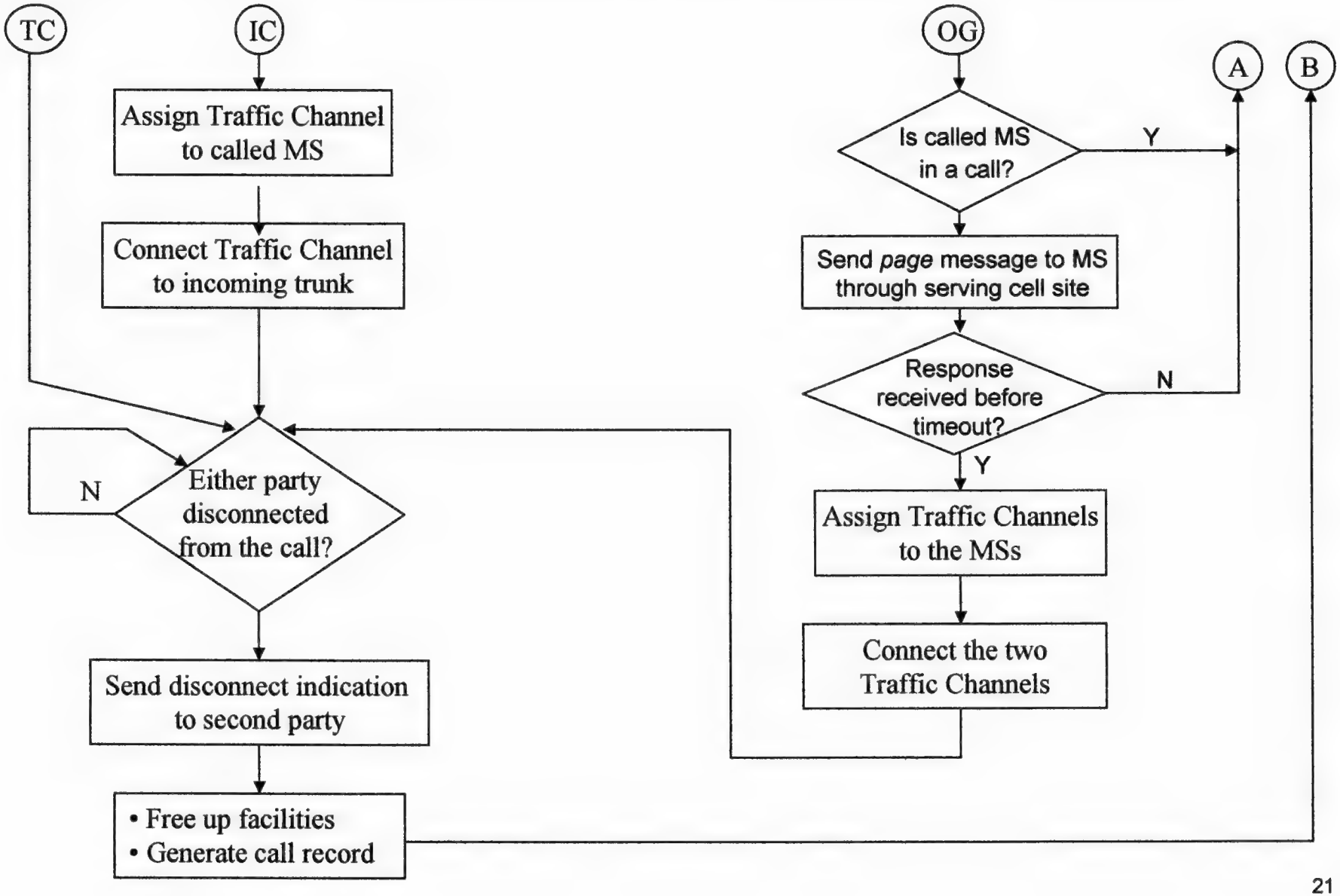
Sample Mobile Station Call Processing Flow Chart



Sample MTSO Call Processing Flow Chart



Sample MTSO Call Processing Flow Chart (cont'd)



Session 4:

Major Cellular Mobile Communication Systems

OUTLINE

- Background to Development of Cellular Systems
- Major First Generation Cellular Systems
- Background to Second Generation Systems
- Advantages of Digital Transmission
- Second Generation Cellular Systems
- Background to Third Generation Systems
- Third Generation Cellular Systems

Background to Development of Cellular Systems

- Big drivers in the development of cellular technology:
  - Capacities of many pre-cellular mobile communication systems had been forecasted to reach saturation by late 1970's
    - Systems in the US were primarily IMTS (Improved Mobile Telephone Service) systems, operating in the VHF band using 30 kHz channels and FM technology
  - Many spectrum regulatory bodies had been pushing for the development of more efficient techniques for utilizing the radio spectrum

FCC don't want give the new spectrum.

- Research on high capacity mobile communication systems carried out simultaneously in various regions of the world
  - AT&T Bell Labs, the inventors of IMTS technology, probably the most involved in the US

all wireless are part of Bell network.

- Resulting cellular concept led to the birth of first generation high capacity mobile systems in the US, Canada, Europe and Japan
  - Systems were all based on analog FM technology just like their predecessors, and used FDD channels

(Frequency Division Duplex) - ① transmit Tradional voice network ② two-way radio communication ③ use a single frequency to transmit & ↓ ② symmetric

(one channel for trasmit one channel for deliver)

- Each channel has fixed Bandwidth
- channel capacity of each frequency is fixed.

Major First Generation Cellular Systems

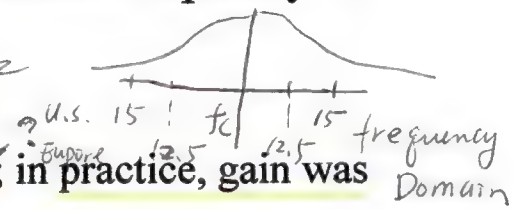
- Systems based on US standards: AMPS (Advanced Mobile Phone Service), Narrowband AMPS (NAMPS), and CDPD (Cellular Digital Packet Data):

30 KHz – AMPS was the first cellular system standard used in the US; 1983

- Developed by AT&T Bell Labs, it was first deployed in Chicago, then quickly replicated in many other cities around the US
- Total spectrum 40 MHz initially in the 800 MHz band, later expanded to 50 MHz (824-849 MHz / 869-894 MHz)
- Primarily designed as a voice communication system; data transmission at up to 9.6 kbps supported through use of external modem

10KHz – NAMPS was introduced initially by Motorola in 1992 to enhance capacity of AMPS systems

- Used 10 kHz channels instead of AMPS' 30 kHz channels
  - In theory should have resulted in 3 times the capacity of AMPS; in practice, gain was about 2 times
- Eventually adopted as a TIA standard, but Motorola remained as primary supplier



– Systems based on these technologies in use in the US, Canada, Mexico and many other parts of the world, except Europe

Raze Technologies

The Advantages of TDD over FDD in Wireless Data Applications

Introduction

The convergence of voice, video and data services is the ultimate goal of many communication service providers. To achieve this goal, technologies associated with the traditional voice dominated network are replaced by newer technologies that accommodate the bandwidth demands of today's consumer. Access schemes, such as Frequency Division Multiple Access (FDMA) and Frequency Division Duplex (FDD), were regarded as innovative technologies when first applied to the requirements of the traditional voice network. Today, however, these technologies are considered obsolete, inadequate to meet the high bandwidth demands and the dynamic nature of the current network that must deliver voice, video, Internet and data services efficiently.

Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are the two most prevalent duplexing schemes used in fixed broadband wireless networks. TDD is the more efficient scheme, however, since it does not waste bandwidth. FDD, which historically has been used in voice-only applications, supports two-way radio communication by using two distinct radio channels. Alternatively, TDD uses a single frequency to transmit signals in both the downstream and upstream directions.

In fixed wireless point-to-multipoint systems that use FDD, one frequency channel is transmitted downstream from a base station to a fixed subscriber terminal. A second frequency is used in the upstream direction and supports transmission from the customer premise to the base station. Because of the pairing of frequencies, simultaneous transmission in both directions is possible. To mitigate self-interference between upstream and downstream transmissions, a minimum amount of frequency separation must be maintained between the frequency pair.

In fixed wireless point-to-multipoint systems that use TDD, a single frequency channel is used to transmit signals in both the downstream and upstream directions.

This paper compares these two duplexing schemes with respect to their use of the available frequency spectrum, suitability for data applications and bandwidth efficiency.

Data Symmetry

Historically, the access network has been optimized for voice traffic that is symmetrical by nature. As data traffic continues to increase in the network, data rates are becoming more and more asymmetrical. Data access inherently is asymmetric, with downstream (from the network to the user) traffic outpacing upstream (from the user to the network) traffic by ratios of 4:1 in business applications and higher in residential applications.

Figure 1 illustrates the anticipated growth in data access rates for Internet service subscribers through 2005. Studies have revealed that Internet based applications dominate the traffic load and Internet connections.

Subscriber Data Access Rates

Tables 1 and 2 detail the usage of data protocols and service application in data access networks. TCP and other protocols such as FTP account for the majority of the protocol usage in data access networks. Internet access clearly dominates network connections.

Data Access Protocol Usage

Data Protocol	% Bytes	% Packets
TCP	88.78	89.8
UDP	1.38	5.93
ICMP	0.11	0.576
Other (FTP)	9.73	13.9

"Analysis of Internet Services and IP over ATM Networks," IEEE Communications Magazine, December 1999

Data Access Service Application Usage

Service Application	% Connections	% Bytes
WEB access	91.71	72.91
SMTP (mail)	4.76	0.24
ProxyWEB	0.68	0.84
FTP	0.55	12.73

FDD systems utilize channel plans that are comprised of frequencies with equal bandwidth. Since each channel has a fixed bandwidth, the channel capacity of each frequency also is fixed and equal to that of all other channels in the frequency band. This makes FDD ideal for symmetrical communication applications in which the same or similar information flows in both directions, such as voice communications.

TDD operates by toggling transmission directions over a time interval. This toggling takes place very rapidly and is imperceptible to the user. Thus, TDD can support voice and other symmetrical communication services as well as asymmetric data services. TDD also can handle a dynamic mix of both traffic types. The relative capacity of the downstream and upstream links can be altered in favor of one direction over the other. This is accomplished by giving a greater time allocation through time slots to downstream transmission intervals than upstream. This asymmetry is useful for communication processes characterized by unbalanced information flow. An obvious application for this technique is Internet access in which a user enters a short message upstream and receives large information payloads downstream.

FDD can be used for asymmetric traffic. However, in order to be spectrally efficient, the downstream and upstream channel bandwidths must be matched precisely to the asymmetry. Since Internet traffic is bursty by nature and the asymmetry is always changing, the channel bandwidth cannot be precisely set in FDD. In this respect, TDD is more efficient. Furthermore, channel bandwidths typically are set by the FCC or limited by the functionality of available equipment. As a consequence, users of FDD systems do not have the option to vary channel bandwidths dynamically in the upstream and downstream directions.

Spectrum Efficiency

Frequency spectrum is an increasingly scarce commodity. This scarcity drives the need to optimize the use of available bandwidth. FDD systems operate on the principle of paired frequencies. A channel plan is devised

that is comprised of downstream and upstream channels, typically defined by the FCC, ITU, or other governing body. FDD channel plans maintain a guardband between the downstream and upstream channels. The guardband is required to avoid self-interference and, since it is unused, essentially is wasted spectrum.

In spectrum allocations such as MMDS, all designated channels are contiguous without specified transition or guardband between go and return channels. Service providers using FDD systems in these situations must create an artificial guardband in order to set aside a portion of the useable spectrum to isolate downstream and upstream frequencies. In this scheme, the spectrum is partitioned into two channel blocks that usually are separated by two vacant RF channels. At MMDS frequencies of 2.5 GHz with 6 MHz channels, this amounts to at least a 12 MHz guardband. As a consequence, two MMDS frequencies are lost. Considering that eight channels are exclusively allocated for MMDS use, the loss of two frequencies is considerable. Compared to the overall 31 channels in the MDS/ITFS/MMDS band, the loss of 2 frequencies to a guardband is about 7% of the available bandwidth. The guardband represents a lost resource and lost revenue for any Internet service provider using FDD.

One alternative is to devise a channel plan in the MMDS band to maintain a minimum transmit/receive separation. However, the licensee may not have access to enough contiguous channels to develop a frequency plan suitable for an FDD deployment.

In contrast, TDD systems require a guard time (instead of a guardband) between transmit and receive streams. The TX/RX Transition Gap (TTG) is a gap between downstream transmission and the upstream transmission. This gap allows time for the base station to switch from transmit mode to receive mode and subscribers to switch from receive mode to transmit mode. During this gap, the base station and subscriber are not transmitting modulated data but are simply allowing the base station transmitter carrier to ramp down, the TX /RX antenna switch to actuate, and the base station receiver section to activate. The TTG has a variable duration that is an integer number of physical time slots (PS). The TTG starts on a PS boundary.

The TTG is equal to following value:

TTG (in seconds) = 2 x (maximum link distance in Km) / (speed of light) + modem TX/RX transition

TTG (in PS) = TTG (seconds) / (4 x symbol rate)

Air Interface Frame with Transition Gap
As an example, if the maximum link distance is 10Km, the speed of light is 3.0e+8 M/sec, and the TX/RX transition is 1 µsec, the TTG is given as:

TTG = 2 x (10 km / 3e+8) + 1 µsec = 67 µsec

Or

TTG = 67 µsec / (4*(1/5 MHz)) = 84 PS

Hence, only 3.4% of the available bandwidth is lost to the TX/RX guardband as compared to FDD.

Hardware Complexity
In FDD systems, two RF channels are in continuous operation at each site; the transmitter operates simultaneously with the receiver. As the downstream and upstream channels typically are close to one another, the transmit signal can overpower the sensitive receiver tuned to the nearby channel. To mitigate self-interference, FDD systems require special filters called duplexers along with careful design of mechanical and electrical shielding to prevent such overload.

The cost of duplexers and implementation of RF shielding increases as the guardband or separation of the two channels decreases. With TDD systems, duplexers and isolation techniques are unnecessary since transmit

and receive channels within a sector never are active simultaneously and cannot interfere with each other. Consequently, TDD hardware is less complex and less expensive.

Frequency Planning

In TDD systems, the transceiver switches between transmit and receive modes based on units of time within the same channel. In many countries, block frequency allocations are made to service providers to provide maximum flexibility in deploying services. In many cases, these allocations are made without regard for the spacing required between transmit and receive frequencies for FDD equipment. An example of this is the MMDS/ITFS or LMDS frequency bands in the United States. Thus, the frequencies allocated for broadband services can become fragmented and non-uniform when FDD rules are applied. Without careful planning, the result can be wasted spectrum. Because of the need for a guardband between the transmit and receive channels, as discussed earlier, some service providers may not have enough bandwidth to provide FDD-based services. TDD systems offer a tremendous advantage over FDD in this respect since they can be deployed with as little as one channel of available TDD spectrum. This eliminates the paired channel allocations required by FDD and allows operators to take full advantage of spectrum allocations that are contiguous, non-contiguous, or small. This makes TDD systems particularly attractive to MMDS operators who have access to only certain MMDS or ITFS channels.

Since the UNII band is unlicensed, the potential for interference is high. Furthermore, MMDS licensees must be concerned with intra-system interference as well as with legacy MDS and ITFS systems. Both TDD and FDD require proper frequency planning for interference mitigation. However, FDD systems require clearing two frequencies: one uplink and one downlink. TDD is concerned only with finding one clear frequency, which simplifies frequency coordination. Both FDD and TDD systems must consider base-base and subscriber-subscriber interference in addition to base-subscriber and subscriber-base interference paths. TDD frequency planning is somewhat different than the FDD approach, yet both require the use of cell planning tools to properly analyze frequency interference.

Dynamic Bandwidth Allocation

One important feature of TDD systems is the recognized, quantifiable performance advantages over FDD systems when transporting bursty data such as Internet traffic. Voice traffic is constant and predictable, whereas data traffic is variable and unpredictable. Because TDD operates in the time domain, unpredictable data that vary in time can be transported more efficiently. Raze Technologies' TDD implementation can dynamically vary the amount of channel capacity allocated to upstream and downstream communications, up to the total capacity of the channel. In other words, it "borrows" time from the transmit direction to increase the return direction as necessary, or vice versa.

The total quantity of bits downloaded over a long time period is the same for both FDD and TDD. However, their delay performance is not. The user does not want a long, time-averaged rate. Instead, the user wants an instantaneous peak rate so that data downloads occur as quickly as possible.

As an example, consider a system that has 20 Mbps capacity available. Disregarding the guardband requirement of FDD implementation, assume that the downstream/upstream ratio is 4:1. This means that 4 Mbps data rate is allocated to the upstream channel while 16 Mbps data rate is allocated to the downstream channel. This is shown in Figure 3.

Initial Capacity Allocations

Assume that new traffic demands require the allocation be changed to a downstream/upstream ratio of 9:1. This means that 2 Mbps data rate needs to be allocated to the upstream and the remaining 18 Mbps data rate needs to be allocated to the downstream traffic. TDD easily adapts to the new demand and allocates capacity as shown in Figure 4. However, FDD cannot easily adapt to this demand. Instead it continues to use 4 Mbps for the upstream traffic and 16 Mbps for the downstream traffic. As a result, 2 Mbps is wasted in the upstream direction, with a shortage of 2 Mbps in the downstream direction. Thus, TDD can dynamically "borrow" bandwidth instantaneously from one direction, while FDD cannot dynamically borrow frequency bandwidth.

Dynamic Bandwidth Demands
To further illustrate the spectrum efficiency of TDD over FDD, consider the Raze SkyFire system operating in the MMDS band. The SkyFire system is capable of dynamically allocating time slots as well as modulation schemes. In the downstream direction, 16- and 64-QAM modulations are used, while in the upstream direction 16-QAM and QPSK are used. Subscribers located closer to the base station will use the higher QAM rates. A single 6 MHz MMDS channel is used.

A comparable FDD system also is capable of using 16- and 64-QAM modulation schemes in the downstream direction but only QPSK in the upstream direction. A pair of MMDS channels is used in the FDD case, for a total of 12 MHz of bandwidth.

Figure 5 shows how TDD spectrum efficiency increases as the downlink to uplink ratio increases, which is typical for Internet applications. FDD spectrum efficiency decreases since the decrease in upstream data results in an over allocation of bandwidth, hence a decrease in the bits per hertz utilized.

Spectrum Efficiency as a Function of Downlink to Uplink Ratio
During a typical day, the upstream/downstream traffic ratio will vary as users come and go and as user groups (business, residential, universities) hit their peak time of usage. This ability to allocate bandwidth dynamically, or "on demand," permits the service provider using TDD to always have the optimal traffic split and provide different grades of service to users within the same sector. Subscribers will be provided bandwidth according to their traffic needs, QoS and Service Level Agreements.

Conclusions
The above discussion has highlighted the advantages of TDD over FDD. These advantages can be summarized as follows:

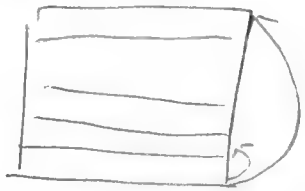
- FDD is an older scheme that was best suited for applications, such as voice, that generate symmetric traffic, while TDD is best suited for bursty, asymmetric traffic, such as Internet or other datacentric services.
- In TDD, both the transmitter and receiver operate on the same frequency but at different times. Therefore, TDD systems reuse the filters, mixers, frequency sources and synthesizers, thereby eliminating the complexity and costs associated with isolating the transmit antenna and the receive antenna. An FDD system uses a duplexer and/or two antennas that require spatial separation and, therefore, cannot reuse the resources. The result is more costly hardware.
- TDD utilizes the spectrum more efficiently than FDD. FDD cannot be used in environments where the service provider does not have enough bandwidth to provide the required guardband between transmit and receive channels.
- TDD is more flexible than FDD in meeting the need to dynamically reconfigure the allocated upstream and downstream bandwidth in response to customer needs.
- TDD allows interference mitigation via proper frequency planning. TDD requires only one interference-free channel compared with FDD, which requires two interference-free channels.

In summary, TDD is a more desirable duplexing technology that allows system operators to receive the most from their investment in spectrum and telecom equipment, while meeting the needs of each individual customer.

FDMA
TDMA

multiple Access (share the spectrum, how to allocate it)

FDMA

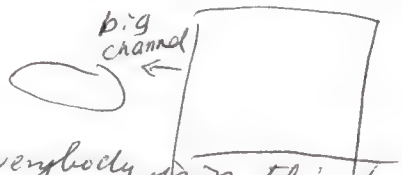


you can change the frequencies
hand-off (move from channel A to B)

TDMA:

time frame / time slot
(分時多工)
four people can use this channel

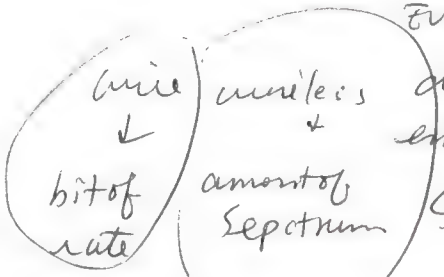
CDMA: users assign the particular



Each antenna have the different code.
Everybody is in this big channel
don't change the channels.
entire spectrum (most efficient)

frequency

more B.W. few channels



CDMA in U.S. Tx Rx
(frequency) ⇒ 25MHz 25MHz
channel
1.25MHz ⇒ 1MHz (at least)
create at least 20 CDMA channels
you use only 1 channel

Speech Codes → from analog to digital

3 classes send speech sample
64Kbps, 32Kbps
- Waveform Coders ← PCM, ADPCM, CVSD → use little spectrum than you could have a lot channels. → use telephone network
- Source Coders ← LPC
(low bit rate Coders) ← Channel Coders - use wireless network
- Hybrid Coders ← 16Kbps

e.g., Korea. KT

TDMA (computer)
(only one company) KT uses too much spectrum & same frequency on each cell

GSM - 2-13 Kbps

perform better
frequency hopping (Europe) try "narrow" channel
spectrum

lease 820MHz-845MHz
the frequency between 820-825

Major First Generation Cellular Systems

- NTT (Nippon Telephone & Telegraph) introduced a system similar to AMPS in Japan in 1979
  - This was the world's first "commercial" cellular system
  - Delay in introduction of AMPS in the US was primarily due to federal proceedings on rules and regulations for service competition and licensing
- CDPD is a 1.5G technology introduced in 1993 to provide a more efficient data handling capability over AMPS systems
  - CDPD was introduced as an overlay packet data network

CDPD

Short for ***Cellular Digital Packet Data,*** a data transmission technology developed for use on cellular phone frequencies. CDPD uses unused cellular channels (in the 800- to 900-MHz range) to transmit data in packets. This technology offers data transfer rates of up to 19.2 Kbps, quicker call set up, and better error correction than using modems on an analog cellular channel.

Typically, one of the AMPS channels in an area would be "upgraded" for CDPD service

Designed to handle data rates up to 19.2 kbps, but in practice supports between 5 and 10 kbps, depending on channel conditions

Uses GMSK (Gaussian Minimum Shift Keying) digital modulation

In the US, CDPD systems are being phased out in favor of more efficient data support schemes

Major First Generation Cellular Systems

- Systems based on UK standards: TACS (Total Access Communication System), NTACS and Japanese TACS (JTACS):
  - TACS was the first cellular system standard used in the UK; 1982
    - It was based on the US AMPS standard, but operated in the 900 MHz band and used narrower channels (25 kHz) benefit to use narrow channel :
    - System capabilities/features similar to AMPS
  - NTACS was the narrowband version of TACS
    - Used 12.5 kHz channels instead of the standard 25 kHz channels
  - JTACS was a version of TACS adapted for Japan
  - Systems based on these technologies still in use in the UK, a few other European countries, Japan and parts of Africa
  - Spectrum later became part of the GSM pan-European digital cellular system spectrum (890-915 MHz / 935-960 MHz)

Major First Generation Cellular Systems

- Systems based on Nordic standards: Nordic Mobile Telephone Systems (NMT 450 and NMT 900):
  - NMT 450 was the first cellular system standard used in the Scandinavian countries – Sweden, Norway, Finland, Denmark; 1981
    - Standard was quite different from AMPS and TACS standards, but also based on analog FM technology
    - Systems operated in the 450 MHz band (453-457.5 MHz / 463-467.5 MHz) and used 25 kHz channels
    - System capabilities/features similar to other analog systems
  - NMT 900 was a 900 MHz band version of the standard, introduced in 1986 to cope with capacity demand
    - Deployed in same frequency bands as the UK-based TACS systems, but used 12.5 kHz channel spacing
  - NMT systems were later deployed in a number of other countries outside Scandinavia
    - Systems based on these technologies can still be found in some countries in Europe, Africa, the Middle East, and Southeast Asia

Background to Second Generation Wireless Systems

- Second generation cellular systems around the world are based on digital wireless technology
  - The over-the-air communications use digital transmission technologies
  - FDD channels still being used
- Primary reasons for the development of digital cellular systems in the major regions of the world were, generally:
  - To increase system capacity in major metropolitan areas
    - Early demand forecasts for cellular service were way underestimated
  - To enhance system quality
  - To allow the introduction of more subscriber features
- In the US and many other parts of the world, digital service is deployed within the same radio spectrum used for analog cellular
  - Some of the analog service channels are "upgraded" to digital channels

Background to Second Generation Wireless Systems (cont'd)

- In Europe, the 900 MHz band was adopted as the new common Europe-wide spectrum allocation for digital cellular service
  - Member countries of the European CEPT wanted to create seamless mobile communication service across Europe
- Digital service was typically initially introduced on a city by city basis, then rolled out over entire service areas
  - Dual-mode phones were introduced to ensure ubiquitous cellular service during the transition phase
- In many parts of the world, including the US, first generation (analog) systems still exist alongside their digital forerunners
  - Most user devices on the market today typically support digital mode only, but dual-mode versions still exist

Advantages of Using Digital Technology

- Permits use of error control techniques
  - ensures more robust communication against interference and noise
    - hence better service quality, fewer dropped calls
- Permits use of sophisticated encryption schemes
  - greatly enhances communication privacy and security
- Can benefit from advances in speech processing technology
  - if desired, voice quality can continue to be improved without major equipment changes
  - system capacity can increase with use of lower bit-rate vocoding
- More efficient and reliable for support of data services

Advantages of Using Digital Technology

- Easier to adapt to digital services offered in the PSTN
  - may allow realization of the Cellular-ISDN concept in the future
- Permits use of more efficient channel access techniques
  - e.g. TDMA, CDMA
  - increases spectrum utilization efficiency and system capacity
    - U.S. TDMA (IS-54 / IS-136): 3 times AMPS capacity
    - U.S. CDMA (IS-95): greater than 10 times AMPS capacity

The more capacity, the better?

Major Second Generation Cellular Systems

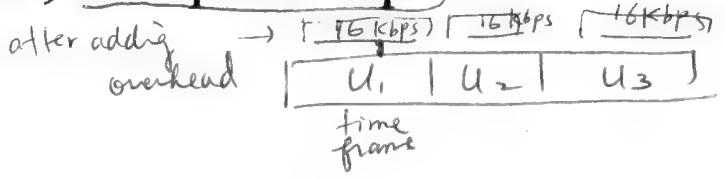
- Standards developed in the US:
  - Digital AMPS (D-AMPS), a.k.a. US Digital Cellular (USDC); 1991
  - cdmaOne; 1993
- Standards originating in Europe:
  - Global System for Mobile Communications (GSM); 1990
    - With GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution)
  - Digital Cellular Systems (DCS-1800 and DCS-1900); 1993
- Standards developed in Japan:
  - Personal Digital Cellular (PDC); 1993
  - Personal Handyphone System (PHS); 1993

Europe (GSM) U.S. (GSM) you can't take your phone in U.S and Europe unless it has two systems in it
GSM - two different frequency (900, 1800)

Major Second Generation Cellular Systems

D-AMPS:

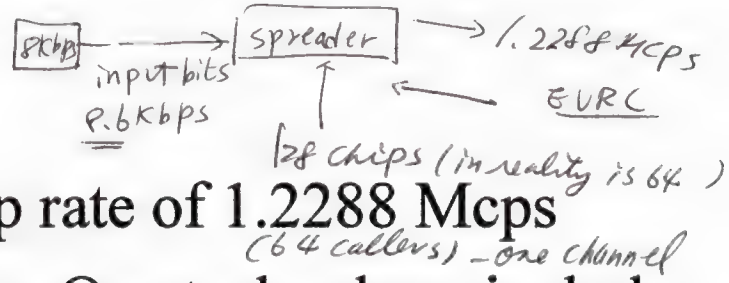
- Operates in same frequency band and channelization structure as AMPS systems
- TDMA multiple access scheme; 6 time slots per frame
  - Supports 3 users per channel with full-rate speech coding (8 kbps), and 6 users per channel with half-rate vocoding
    - In practice, only full-rate coding is in use; research into half-rate speech vocoding still ongoing
- Traffic channel data rate: 48.6 kbps
- Major US wireless operators using D-AMPS technology include AT&T Wireless and Cingular Wireless (SBC, BellSouth)
- D-AMPS systems can also be found in many other parts of the world, except Europe



Major Second Generation Cellular System Standards

cdmaOne:

- Operates in same frequency band as AMPS, but on dedicated spectrum
  - Uses direct sequence spread spectrum (DS-SS) technology
  - Requires 1.25 MHz of spectrum for each channel
  - Frequency reuse factor: N = 1
  - Variable-rate speech coding: 1 – 8 kbps
- CDMA multiple access technique; chip rate of 1.2288 Mcps
- Major US wireless operators using cdmaOne technology include Verizon Wireless and Sprint PCS
- cdmaOne systems can also be found in many other parts of the world, except Europe
  - South Korea's KT has probably the largest cdmaOne network in the world



Major Second Generation Cellular System Standards

GSM (and GPRS and EDGE):

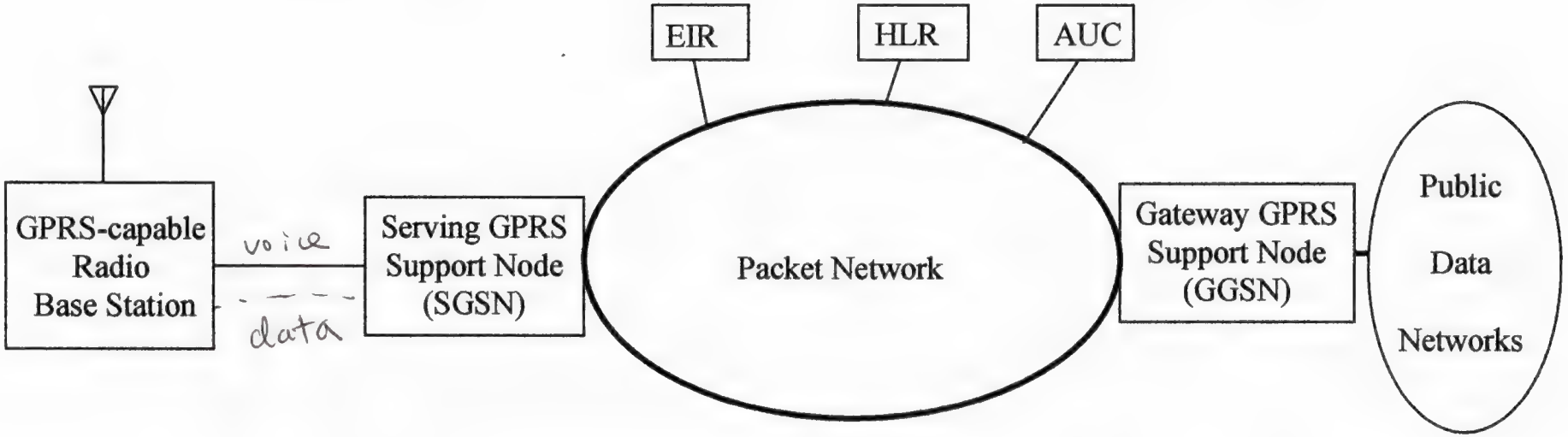
- GSM is based on TDMA technology - 13.2 kbps (Full Rate)
  - Frame structure has 8 (6) time slots on a 200 kHz (30 kHz (U.S.)) channel (Europe)
  - Traffic channel data rate: 270.8 kbps
- GSM is used throughout Europe and in many other parts of the world
  - Worldwide, it serves more subscribers than any of the other digital system technologies
- T-Mobile is probably the largest US wireless operator using GSM technology
  - Pacific Bell Mobile (now part of SBC) was among the first to introduce GSM service into the US marketplace
  - Although late in their introduction in the US, systems based on GSM technology can nowadays be found in most parts of the country

Major Second Generation Cellular System Standards

General Packet Radio service enable networks offer "always-on"

GSM (and GPRS and EDGE):

- GPRS is an overlay packet-based data network originally designed for GSM systems
  - Provides connectivity to X.25 and IP networks, and supports "always on" connections



  - GPRS is specified to support an aggregate data rate of up to 171 kbps, however in practice top rate is currently in the neighborhood of 100 kbps

Major Second Generation Cellular System Standards

GSM (and GPRS and EDGE):

- GPRS is considered a 2.5G upgrade technology
- In addition to GSM operators, a number of D-AMPS systems have announced plans to enhance their networks using GPRS
  - Seen as a way to evolve such networks towards 3G capabilities
- EDGE is a more advanced data upgrade to the GSM standard
  - Implementation requires use of new hardware and software at base stations
    - EDGE-capable base stations typically can process EDGE traffic as well as pure GSM traffic
  - EDGE is designed to support aggregate data rates up to 384 kbps
    - Option exists to combine multiple radio channels (bandwidth-on-demand) to provide data rates in the Mbps range
  - EDGE uses the packet networking capability of GPRS, and is being considered by many D-AMPS operators as an upgrade path towards 3G

Major Second Generation Cellular System Standards

PDC and PHS Systems:

- Used primarily in Japan
- PDC is much like DAMPS
- PHS air interface standard was developed by the Japanese R&D Centre for Radio Systems (RCR)
  - A TDMA system based on 300 kHz channels
  - Uses same modulation scheme as DAMPS, but channel rate is 384 kbps
  - Employs 32 kbps ADPCM for voice
  - System designed for microcellular applications
  - Handoffs only at walking speeds

Third Generation (3G) Wireless Systems

- Main driver: the International Telecommunications Union (ITU), an organization within the United Nations
- Desire of the ITU was the creation of a global ubiquitous wireless telecommunications network
  - Seen as a way to overcome the terminal and personal mobility problems in the existing multi-standard regional wireless environment
    - Global subscriber identification number system envisaged
  - Scale economics would make wireless affordable to third-world countries
    - Help bridge the huge telecommunications gap with the developed world
    - In turn would foster economic development in those countries
  - A satellite component to be part of the global third generation network
    - Seen as a way to quickly and cost-effectively extend basic telecommunications service to the many isolated and remote communities of the third world

Third Generation (3G) Wireless Systems

- Work on 3G began in 1984 under a Task Group created by the ITU Radiocommunications sector (ITU-R)
  - Task Group 8/1 was tasked with developing service concepts and technical Recommendations for the target global wireless network
  - Many nations and individual companies participated in the activities of the Task Group
- Worldwide 3G system is currently referred to as the International Mobile Telecommunication System 2000 (IMT-2000)
- 3G networks are intended to support high data rates for efficient support of multimedia, video and data traffic in addition to voice
  - The following 3 data rates have been specified in the Recommendations:
    - 144 kbps for mobile applications at up to vehicular speeds
    - 384 kbps for portable applications involving motion at up to pedestrian speeds
    - 2.048 Mbps for stationary applications (E1)

Third Generation (3G) Wireless Systems

- The ITU goal of having ubiquitous wireless service based on a single global wireless standard has not been achieved so far because of the following reasons:
  - No common band of radio spectrum has been found that can be dedicated to 3G service in all countries of the world
    - The bands 1885 – 2025 MHz and 2110 – 2200 MHz have so far been designated by the ITU for IMT-2000 systems (WARC 92 and WRC 97)
    - However, uncoordinated pre-3G uses of parts of this spectrum have made it impossible to align all countries within a single band
      - the US uses the bands 1850 – 1990 MHz for PCS (Personal Communications Service);
      - in Europe, DECT systems operate in the bands 1880 – 1900 MHz;
      - in Japan, PHS service uses the band 1890 – 1920 MHz
  - Regional "politics" made it impossible for the ITU to adopt a single radio interface standard for all regions of the world

Third Generation Wireless System Standards

- The ITU-R Working Party on 3G Radio Access standards has adopted the following air interface Recommendations:
  - IMT-Direct Spread (**IMT-DS**), a.k.a. W-CDMA, UMTS:
  - IMT-Multi-Carrier (**IMT-MC**), a.k.a. cdma2000:
  - IMT-Time Code (**IMT-TC**), a.k.a. SCDMA
  - IMT-Single Carrier (**IMT-SC**), a.k.a UWC-136:
  - IMT Frequency Time (**IMT-FT**)
- The first two standards will likely dominate the 3G network space
  - IMT-DS because of its support from the GSM community; IMT-MC because of its compatibility with current cdmaOne systems
  - The dissolution of UWC organization casts doubt on success of IMT-SC
- Although specific product implementations will vary by equipment manufacturer, it is generally expected that 3G systems will be designed around IP core networks

Session 5:

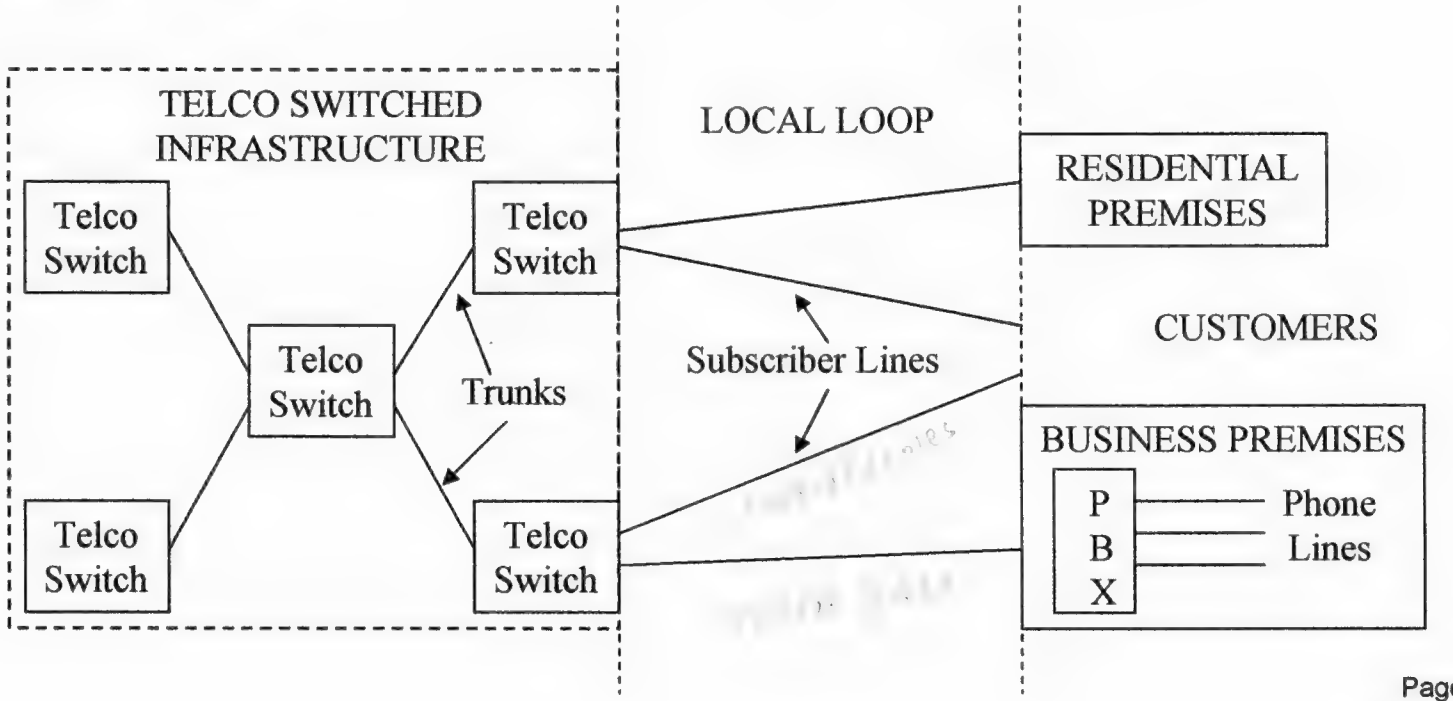
Wireless Local Loop and
Broadband Wireless Access Systems

OUTLINE

- Local Loop
- Wireless Local Loop (WLL) Systems
- Broadband Wireless Access Systems
- Multi-channel Multipoint Distribution Service (MMDS)
- Local Multipoint Distribution Service (LMDS)
- Fixed Broadband Wireless Access Standards
- MMDS vs. LMDS: Coverage and Costs
- MMDS vs. LMDS: Data Rates and Applications

Local Loop

- *Local loop* is a telecommunications industry terminology used to refer to the transmission infrastructure used to connect telecom service customer premises to the switched telephone network
  - For residential customers, twisted-pair copper wires have been and continue to be the standard facilities in the local loop
  - For business customers, twisted-pair copper wires, coaxial cables, and optical fibers are in use



WLL Systems

- Wireless local loop (WLL) systems are fixed wireless systems traditionally used as alternative distribution networks in the provisioning of telecommunication services to subscribers
  - WLL systems use radio transmission in place of copper wire, coaxial cable and optical fiber in the local loop
  - Both residential and business customers can be served using these systems
- Telecom companies have typically used WLL systems in rural areas where it is not cost-effective to lay down cables to customer premises
  - The Basic Exchange Telecommunication Radio Service (BETRS) is an example of a popular WLL system for telephony applications
- The term WLL is nowadays being used in some literature to represent all fixed wireless distribution systems, including fixed broadband wireless access systems

Broadband Wireless Access (BWA) Systems

- BWA systems provide high-speed wireless connectivity between fixed sites for sending and receiving voice, data and video traffic in a manner similar to wireline networks
  - Because they are fixed systems, they are less susceptible to transmission impairments such as encountered in mobile networks
    - They can therefore achieve much higher transmission speeds (in the Mbps range)
  - Fixed BWA systems are sometimes referred to as *wireless DSL* DSL filter to get rid of noise.
- Competing technologies in the wired world include DSL, hybrid fiber coaxial (HFC), and fiber-to-the-home (FTTH) services fiber DSL in Korea
  - DSL uses twisted copper pairs over a distance of no more than 3.4 miles from the PSTN central office not close to central office
    - The farther away a user is from the CO, the smaller the bandwidth available
  - HFC uses a shared transport medium based on the cable TV infrastructure
    - Performance is a function of the number of active users OC-192 10gbps
  - FTTH can provide up to (OC-3 fiber data rates (155 Mbps) to the user OC-1 (51 Mbps)
    - However, fiber is very expensive to install and availability is limited

Broadband Wireless Access (BWA) Systems

- Advantages of BWA over the wired broadband access technologies:
  - BWA systems can be deployed very rapidly to serve many customers
  - BWA systems are simpler to maintain and more reliable
    - No chance of service outage due to accidental cutting of cables by construction crews, etc.
  - Many places do not have access to the wired last-mile access technologies
    - Rural areas with low population densities, areas with aged communication infrastructure, third world countries, etc.
- Major application areas for fixed BWA systems include:
    - Always-on Internet access service
    - Corporate converged networks
      - Integrating voice, video and data traffic onto one network
    - Multi-tenant unit services
      - Multiplexed telephony, Internet access, and video services
    - Wireless cable TV distribution service

Broadband Wireless Access (BWA) Systems

- Currently two fixed broadband wireless services are available in the US:
  - MMDS (Multi-channel Multipoint Distribution Service)
  - LMDS (Local Multipoint Distribution Service)

Multi-channel Multipoint Distribution Service (MMDS)

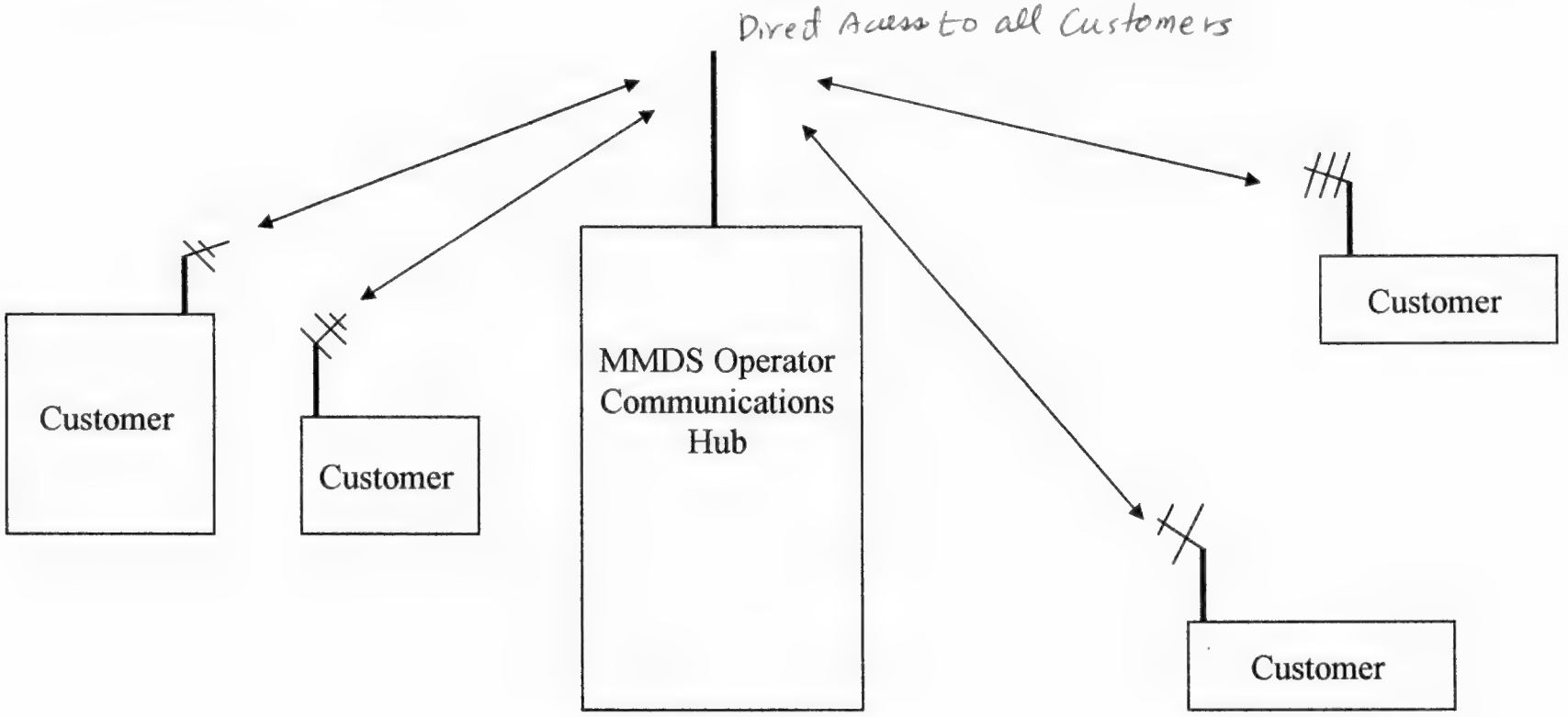
- MMDS is a fixed BWA service with origins in the 1970's
  - Original service was called Multipoint Distribution Service (MDS)
    - MDS was used strictly for TV transmission to deliver service into rural areas not reached by broadcast TV or cable
    - MDS was initially allocated 12 MHz of RF spectrum which supported 2 analog TV channels, each with a bandwidth of 6 MHz
  - Over the years, RF spectrum has been increased to current level of 78 MHz contained in 5 frequency bands in the range 2.15 GHz to 2.68 GHz:

2.1500 – 2.1620 GHz	(i.e. 12 MHz)
2.5960 – 2.6440 GHz	(i.e. 48 MHz)
2.6500 – 2.6560 GHz	(i.e. 6 MHz)
2.6620 – 2.6680 GHz	(i.e. 6 MHz)
2.6740 – 2.6800 GHz	(i.e. 6 MHz)

  - Use of the above frequency bands and the transmit power allowed by the FCC permits a single transmitter (base station) to cover a 35-mile radius
    - An unobstructed path is required between transmitter and subscriber antennas
      - Directional antennas are typically used at the subscriber end

Multi-channel Multipoint Distribution Service (MMDS)

- Like broadcast television, MMDS signals are transmitted from very high towers, usually located on mountain tops or tall buildings
  - This is so as to cover the widest possible area and to ensure line-of-sight with customer locations



Multi-channel Multipoint Distribution Service (MMDS)

- The Telecom Act of 1996 greatly increased flexibility in the use of the MDS frequency bands
  - It permitted multi-channel services (hence the new term MMDS) and 2-way digital communications, excluding only mobile communication services
    - Subsequently, Sprint and MCI WorldCom made major investments to gain majority control of the MMDS spectrum in the US
- In two separate rulings in 1995 and 1998, the FCC allowed use of digital transmission utilizing CDMA, QPSK, and QAM schemes
  - Currently, this allows data transfer rate of about 10 Mbps per channel
  - Ongoing developments in OFDM (Orthogonal Frequency Division Multiplexing) frequency management technique may allow higher data rates
    - OFDM is like standard FDM, however it utilizes a mathematical process called *Fast Fourier Transform* (FFT)
      - This enables frequency sub-bands to overlap without loss of individuality
      - Overlapping sub-bands result in more efficient use of the spectrum

Multi-channel Multipoint Distribution Service (MMDS)

- Currently, MMDS spectrum is being used primarily for delivery of multi-channel video programming similar to cable TV
  - For this reason, MMDS is also referred to as *wireless cable*
- Deployment of MMDS systems in the US was almost at a standstill from 2000 to 2001 due to uncertainties in spectrum allocations
  - The FCC was considering relocation of the MMDS and Instructional Television Fixed Service (ITFS) to higher frequency bands, around 26 GHz
    - Recall that an ITU World Radiocommunications Conference had identified the frequencies 2.1 GHz to 2.2 GHz as candidates for global 3G systems
- With the spectrum issue settled, use of MMDS for high-speed Internet access is expected to pick up
  - This should offer serious competition to DSL and cable services
    - High-speed Internet service via MMDS is already being offered in nearly 50 markets across the US, so far mostly in areas lacking DSL or cable service
  - MMDS is expected to be available on a nationwide basis in the near future

Local Multipoint Distribution Service (LMDS)

- LMDS is a relatively new fixed BWA point-to-multipoint service for two-way transmission of voice, data, and video services
  - In the US, LMDS has been allocated spectrum in the 27 GHz to 31 GHz frequency range as shown below:

    A-Block: (1150 MHz of total spectrum)

27.5 – 28.35 GHz	(i.e. 850 MHz)
29.1 – 29.25 GHz	(i.e. 150 MHz)
31.075 – 31.225 GHz	(i.e. 150 MHz)

    B-Block: (150 MHz of total spectrum)

31.0 – 31.075 GHz	(i.e. 75 MHz)
31.225 – 31.3 GHz	(i.e. 75 MHz)

    - The 1.3 GHz total spectrum allocated to LMDS is one of the largest amount of spectrum devoted to any one service
  - Availability of broad bandwidth means LMDS can deliver services at much higher data rates than possible with MMDS

Local Multipoint Distribution Service (LMDS)

- In the US, a total of 986 LMDS licenses were awarded by the FCC through auctions held between February 18 to March 25, 1998
  - Incumbent local exchange carriers (ILECs) and cable television companies are restricted from owning A-Block licenses in their authorized service areas
    - This is so as to foster competition
- There is no consensus regarding what LMDS will ultimately be used for since it can offer such a wide variety of applications
  - Major areas of opportunity are seen as:
    - Video services, including TV broadcasts and interactive TV
    - High-speed data, including Internet access and LAN interconnections
    - Voice services
  - To date, carriers that have deployed LMDS systems in one form or another include Nextlink, Teligent, Winstar, and CellularVision
    - Nextlink owns about 95% of the LMDS spectrum in the top 30 US markets nationwide
    - CellularVision is using LMDS to deliver 49 channels of cable TV service to parts of NY City that have resisted deployment of coaxial cable

Fixed Broadband Wireless Access Standards

- With growing interest in fixed wireless broadband services, the industry recognized a need to develop standards for such systems
  - Standards lead to cost-effective network products, low-cost consumer products, and advance consumer acceptance of new technologies
- In the US, IEEE 802.16 is the interoperability standard being developed for fixed broadband wireless access systems
  - IEEE 802.16.1: Air interface for 10 to 66 GHz frequency range
    - Applies to systems like those for delivering LMDS services
    - Working group is the farthest along, and attracts most industry interest
  - IEEE 802.16.2: Coexistence of Broadband Wireless Access Systems
    - Specifications will ensure non-interfering coexistence of BWA systems
  - IEEE 802.16.3: Air interface for licensed frequencies in the 2 to 11 GHz range
    - Applies to systems like those for delivering MMDS services
- In Europe, the HIPERACCESS standard is being developed by the standards committee for Broadband Radio Access Networks (BRAN)
  - Systems in Europe operate in the 40.5 – 43.5 GHz band

Fixed Broadband Wireless Access Standards (cont'd)

- IEEE 802.16.1 is designed to support the following bearer services:
  - One-way digital audio/video streams to subscribers: For broadcast radio, cable TV, and satellite TV applications
  - Digital telephony: Similar to wireless local loop service
  - Transport of Frame Relay frames, ATM cells and IP datagrams: As part of an overall Frame Relay, ATM or IP-based network such as the Internet
  - Bridged LAN service: For transfer of data between two LANs
  - Backhaul for digital wireless telecommunication networks: e.g. cellular networks
- IEEE 802.16.3 is designed to support the following bearer services:
  - Voice transport: A packet-based service for providing equivalent service to that of the PSTN
  - Data transport: Provides transport services for IP-based networks
  - Bridged LAN service
- Essentially, LMDS can deliver all the services that MMDS can and more, and at even higher speeds and bandwidth capacity

MMDS vs. LMDS: Coverage and Costs

- MMDS has advantages over LMDS in the areas of coverage range, network deployment cost, and subscriber equipment cost
  - Advantages arise because of MMDS use of lower frequencies than those used by LMDS
    - At the 2 GHz operating band of MMDS systems, a single base station can cover a range of about 35 miles radius (i.e. over 3800 square miles)
      - This is typically sufficient for most service areas
    - In the millimeter wave region of LMDS systems, propagation characteristics limit the cell coverage area to around 3 miles (i.e. under 30 square miles)
      - This necessitates the use of many base stations and cellular-like frequency re-use planning to cover any reasonable size city
    - Components in the 2 GHz band are less expensive than those in the LMDS band
      - This is because of maturity of 2 GHz band technology and volume
  - It is estimated that LMDS requires 5 – 10 times the investment for MMDS
- Nevertheless, LMDS systems are still more cost-effective than fiber or coaxial cable systems
  - Wireless solutions are fast to deploy and do not involve cable-laying costs

MMDS vs. LMDS: Data Rates and Applications

- LMDS has a significant advantage over MMDS in the data rates it can support
  - Whereas MMDS can support data rates up to 10 Mbps, LMDS can support up to 200 Mbps
    - This may make LMDS cost-effective and attractive for large commercial customers
- Nevertheless, cost considerations make MMDS the technology of choice for those who do not need the very high data rates of LMDS
  - Residential customers; especially those with no access to cable or DSL service
  - Small to medium-sized businesses and branch offices
  - Businesses that are located away from primary business districts, in areas that are years away from having DSL or fiber installations
- Only time will tell the long-term market split between LMDS and MMDS services

Session 6:

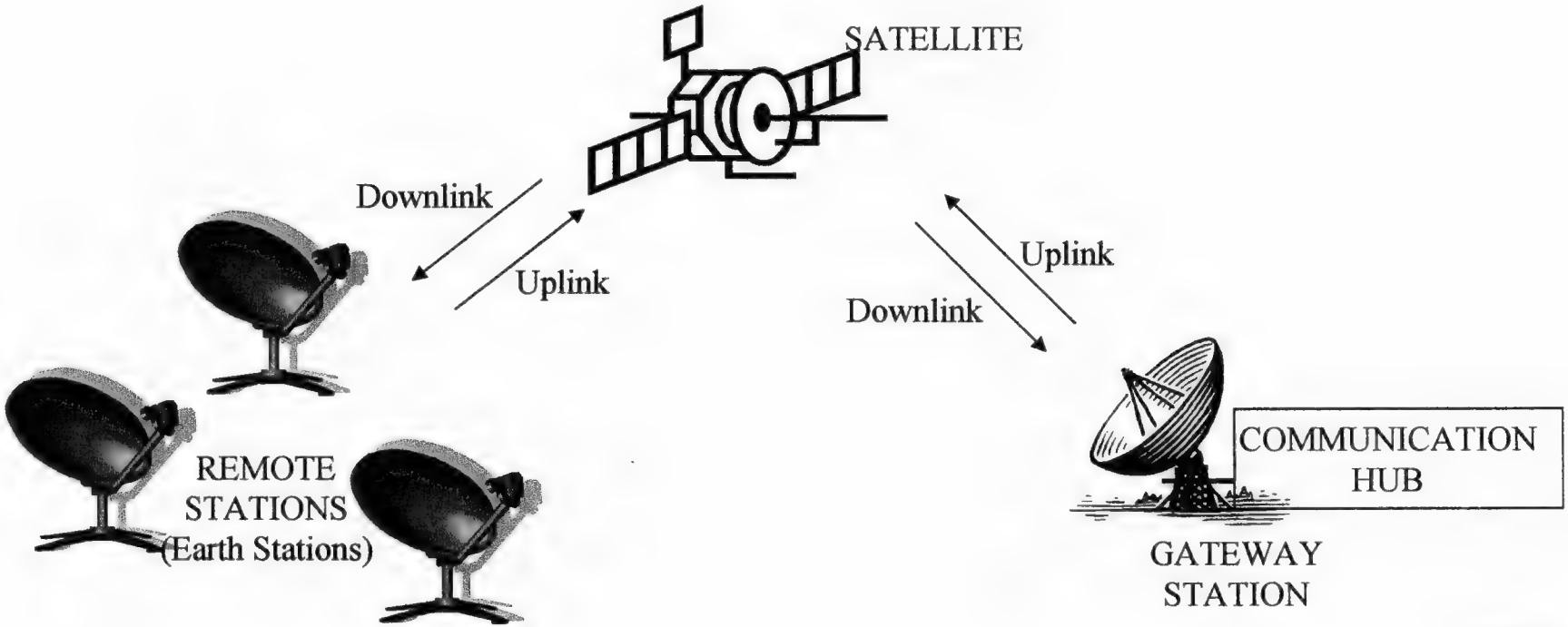
Satellite Communication Networks

OUTLINE

- Introduction to Satellite Communications
- Fixed Satellite Communication Systems
- Mobile Satellite Communication Systems

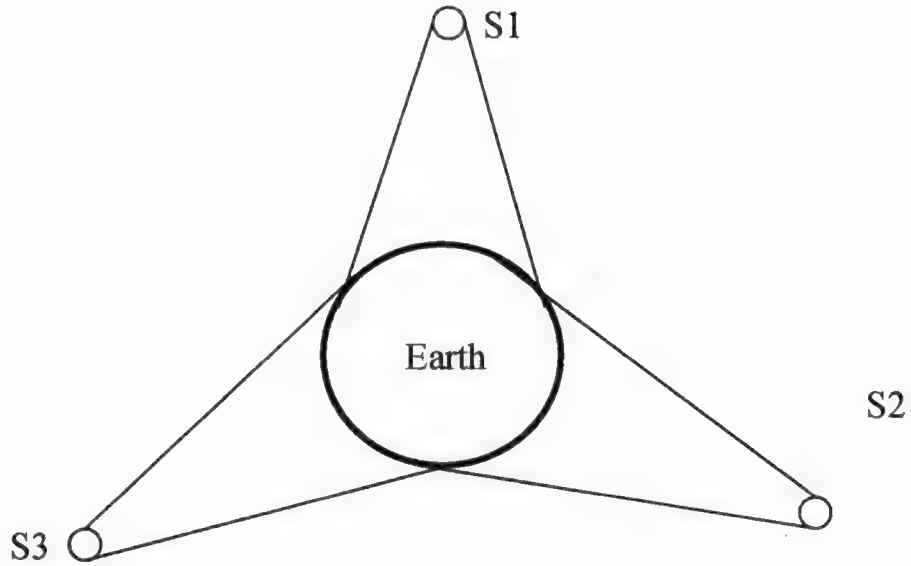
Introduction to Satellite Communications

- Satellite communication networks use satellites up in the sky as repeaters to extend network services to customers over a large part of the earth's surface
  - Ideal for communicating over very long distances, and for extending communication services into areas which are otherwise uneconomical to serve via terrestrial means



Introduction to Satellite Communications

- The amount of area covered by any single satellite depends largely on its altitude above the earth's surface
  - At an altitude of approximately 36,000 km above the equator, a set of three satellites spaced at 120° from each other can provide near full earth coverage
    - Coverage is typically not available beyond about 76° latitude



  - At very low altitudes, the coverage area of each satellite becomes small, and the number of satellites required to cover the earth increases

Introduction to Satellite Communications

- Kepler's laws of planetary motion define the shape of orbits and the orbital period of satellites, and Newton's laws of motion and gravitation explain the reason for this behavior
  - A satellite at 36,000 km has an orbital period of about 24 hours, and appears to be stationary relative to observers on earth
    - Satellites at this altitude follow a circular orbit around the earth, and are referred to as ***geostationary*** or ***geosynchronous*** satellites, as they revolve around the earth at the same rate as the earth's rotation on its axis
    - Geostationary satellites are always directly above the equator, and their orbit therefore has an inclination of 0° with respect to the equator
      - This orbit is referred to as the *equatorial* orbit
  - Non-geostationary satellites generally follow circular or slightly elliptical orbits with inclinations of between 0° and 90°
    - When the inclination is 90°, the orbit is called a *polar* orbit
    - The other orbits are referred to as *inclined* orbits

"Teledesic" – router on the satellite

* satellite switch can switch in the air

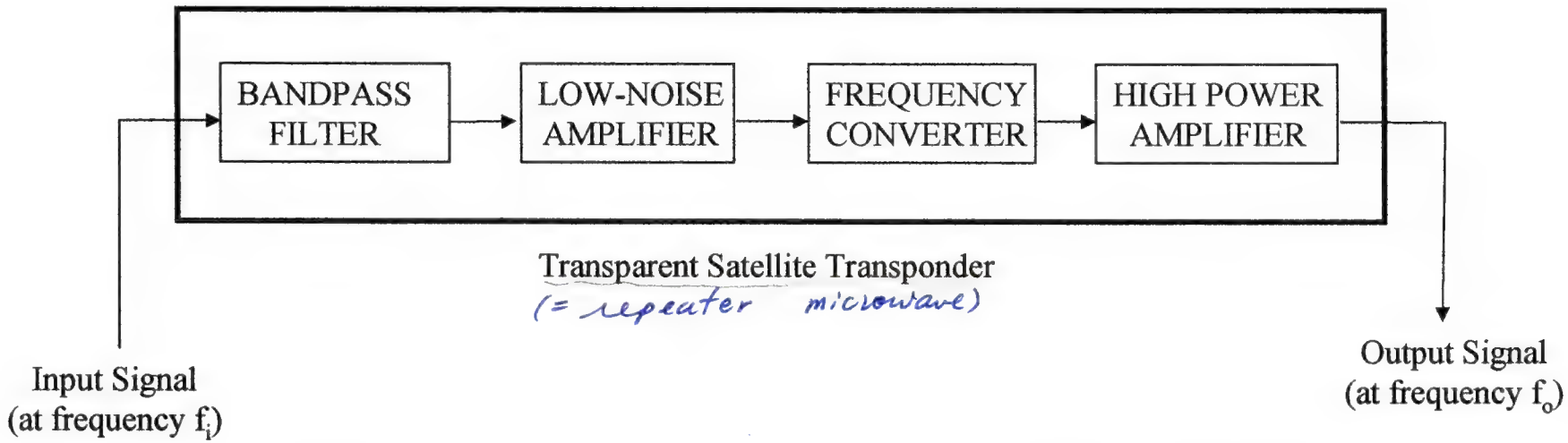
Introduction to Satellite Communications

66

- Orbits for communication satellites can be categorized according to their altitude:
  - Geostationary Earth Orbit (GEO)
    - Satellite altitude of approximately 36,000 km above the equator
  - Medium Earth Orbit (MEO)
    - Satellite altitudes ranging between 10,000 km and 12,000 km above the earth
  - Low Earth Orbit (LEO)
    - Satellite altitudes in the 750 km to 1500 km range above the earth
- The higher the satellite is above the earth's surface, the longer the propagation path, and hence the longer the path delay
  - At the geostationary altitude, a one-way path delay of about 270 msec results
  - MEO satellites have a one-way path delay in the range of 30 – 100 msec
  - LEOs have one-way path delay in the order of 5 – 10 msec

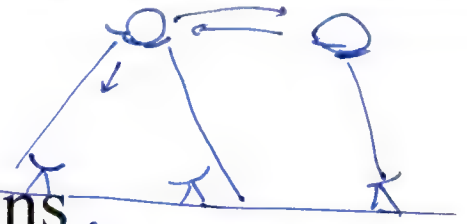
Introduction to Satellite Communications

- The main communication system of a satellite (payload) comprises an antenna system and a *transponder*
- Two types of transponders are used on-board modern satellites: *transparent* and *regenerative* transponders
  - A transparent (a.k.a. non-regenerative) transponder is functionally equivalent to a microwave repeater
    - It receives communication signals on its receive frequency band, amplifies them, and re-transmits them on its transmit frequency band

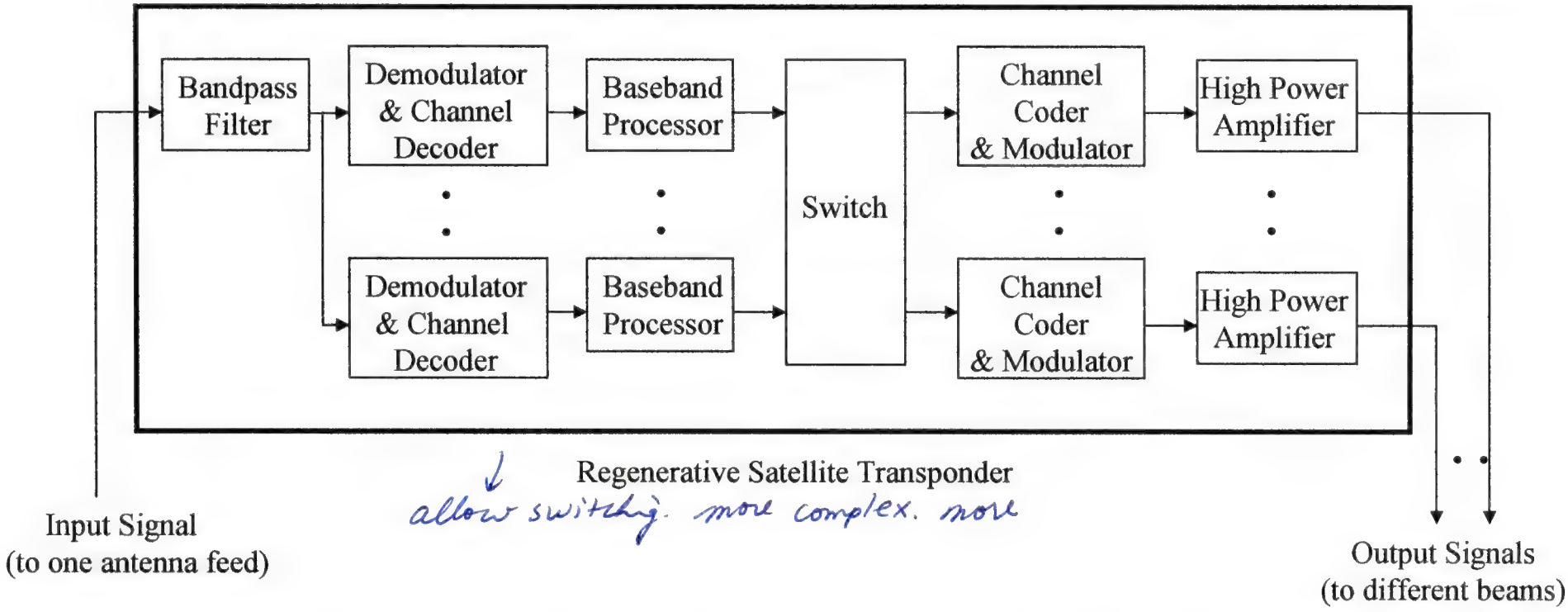


  - Most commercial satellites in service today use transparent transponders

Introduction to Satellite Communications



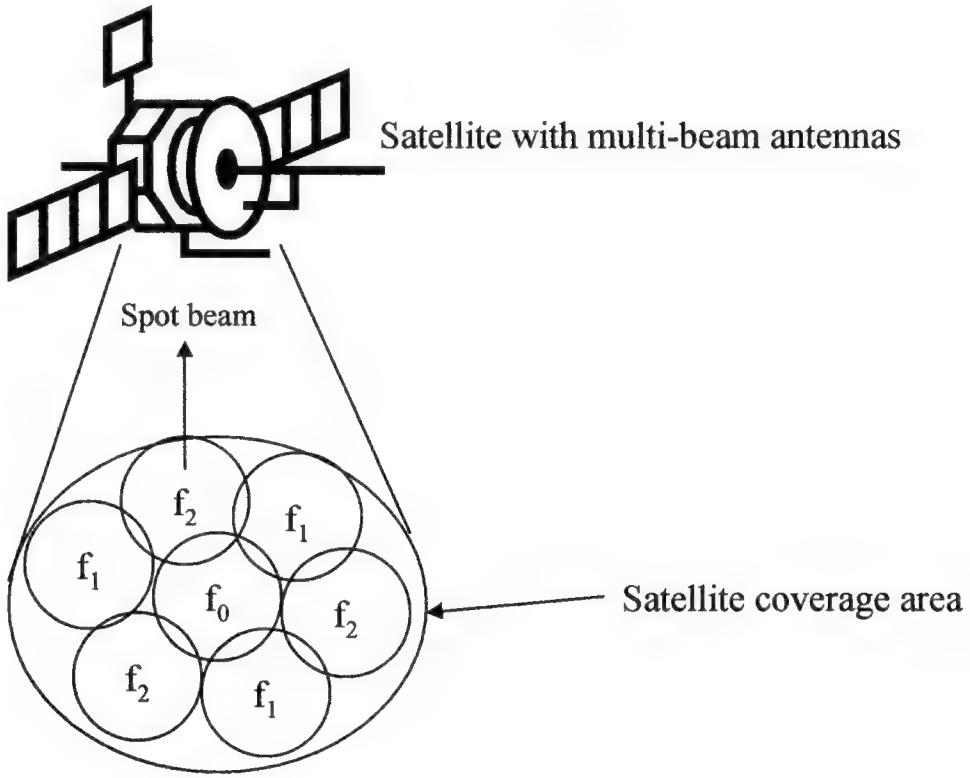
- A regenerative transponder performs essential signal processing to enable on-board signal switching between beams
  - This involves a *regeneration* of the baseband signal and use of multi-beam satellite antennas



- On-board switching capability provides considerable efficiency in traffic routing
- Signal regeneration results in significant performance advantage over transparent method
  - Estimated to yield an average of 8 dB performance advantage

Introduction to Satellite Communications

- Multi-beam satellite antennas enable use of cellular-like frequency reuse concept in satellite communication systems
  - Spot beams from satellites are used to create cells on the earth's surface
  - Because of the large distances used in satellite cells, frequencies can be re-used in every third cell



Fixed Satellite Communication Systems

- Communication satellites for non-mobile applications are primarily deployed in the GEO orbit
- Three frequency bands have been assigned to these systems:
  - C-band (4/6 GHz band): 3.7 – 4.2 GHz (downlink); 5.925 – 6.425 GHz (uplink)
  - Ku-band (12/14 GHz band): 11.7 – 12.2 GHz (downlink); 14.0 – 14.5 GHz (uplink)
  - Ka-band (20/30 GHz band): 17.7 – 21.7 GHz (downlink); 27.5 – 30.5 GHz (uplink)
  - C-band was the first to be used and is now overcrowded
    - Spectrum use is shared with terrestrial microwave systems, resulting in interference problems in some areas
  - The Ku-band is not yet congested and is not shared with terrestrial systems
    - However rain attenuation is a big problem for systems in this band
  - The Ka-band does not have much traffic yet, partly due to high equipment costs
    - Rain attenuation and tropospheric scintillation are also significant in this band

Fixed Satellite Communication Systems

- Antennas used for fixed satellite communications are primarily of the parabolic reflector (dish) type
  - This is because of the high frequencies used and the need for high directivity with the transmitting antenna
    - At very high frequencies, the RF signal is more efficiently transported in hollow tubes called *waveguides*, instead of wire or cable conductors
      - This is due to the *skin-effect* phenomenon
  - Use of a parabolic reflector fed from its focal point provides a very efficient way of directing the electromagnetic wave into the desired area
- Size of dish antennas used in fixed satellite communication systems varies depending on the operating frequency band and application
  - C-band antennas are the largest and Ka-band antennas are the smallest
  - Antennas for low capacity use (e.g. 2.4 kbps to 56 kbps) can generally be made physically smaller than those for high speed applications

Fixed Satellite Communication Systems

- Fixed satellite communication systems are used mainly for:
  - Long distance telecommunication services
  - Wide-area private/corporate data networking; using very small aperture (VSAT) terminals
  - Direct-to-home TV broadcasting services (DBS)
  - Remote TV signal backhauling (from transportable satellite earth stations)
- The INTELSAT satellite (above Ocean) system is probably the most important in global telecommunications
  - Prior to deployment of under-the-ocean fiber optic communication systems, INTELSAT system carried all trans-oceanic telecommunications traffic
    - System uses three sets of satellites positioned over the Pacific, Atlantic, and Indian oceans
  - Early satellites used transparent transponders; newer INTELSAT VI and VII satellites employ on-board switching

Fixed Satellite Communication Systems

- Many nations use domestic satellite systems for long distance telecommunications and wide-area distribution of other services
  - Canada was the first country to deploy a domestic satellite communication system, in 1965
    - The Anik series of satellites is used for high-capacity trunking among major Canadian population centers, thin-line connectivity to sparsely populated areas such as the far north, and TV signal distribution
  - There are currently about 150 communication satellites in the GEO orbit, belonging to different countries
  - Some nations team together to operate "regional" satellite systems
    - Examples:

      PANAFSAT – Pan-African Satellite Communication System

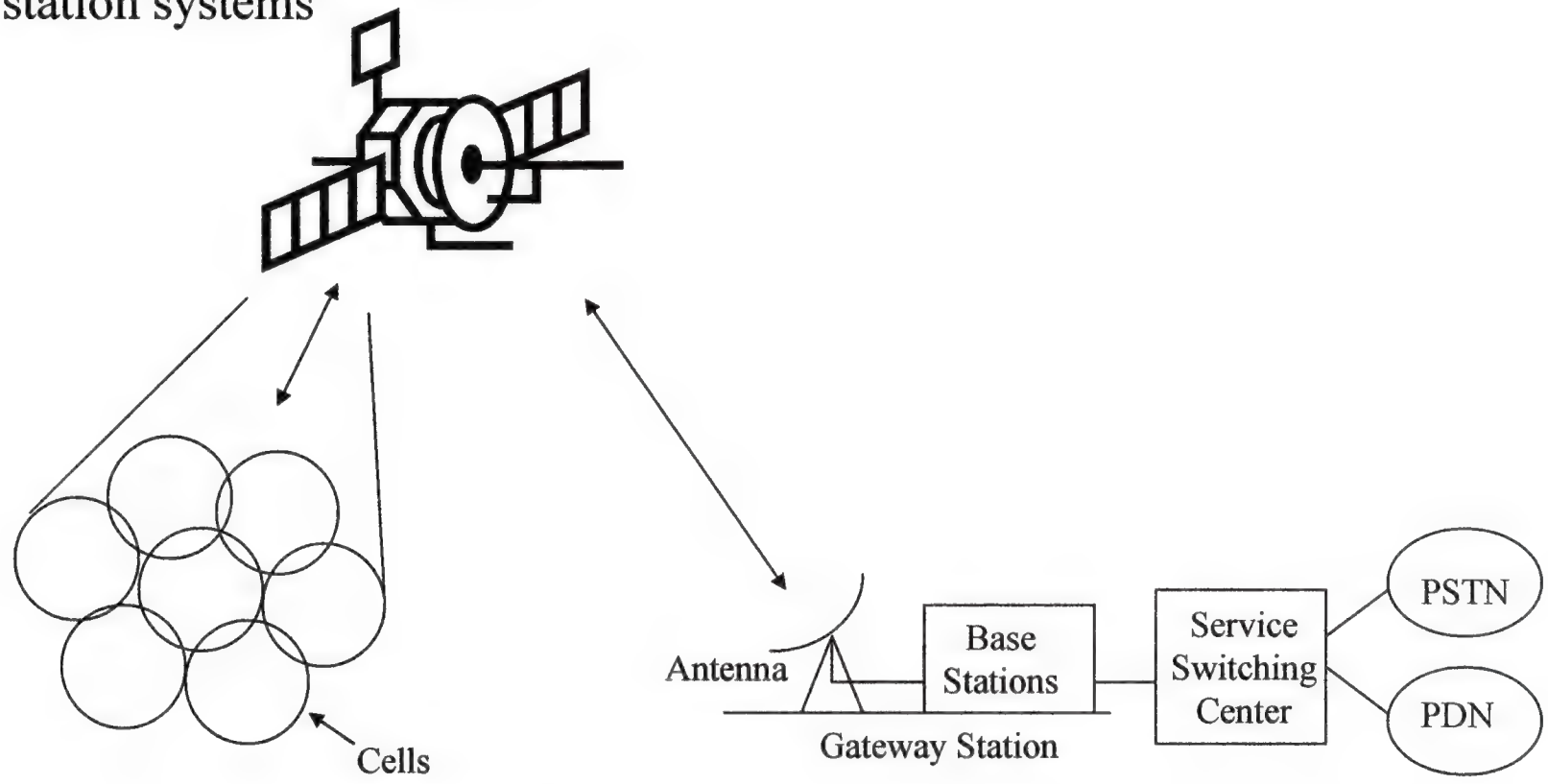
      ARABSAT – Used by a number of Arab countries in the Middle East and North Africa

      ASIASAT – Used by countries in the Far East

      EUTELSAT – European Telecommunication Satellite System

Mobile Satellite Communication Systems

- Mobile satellite communication systems (MSS) are satellite-based systems which support user mobility
  - Satellites in these systems perform as extensions of the fixed network base station systems



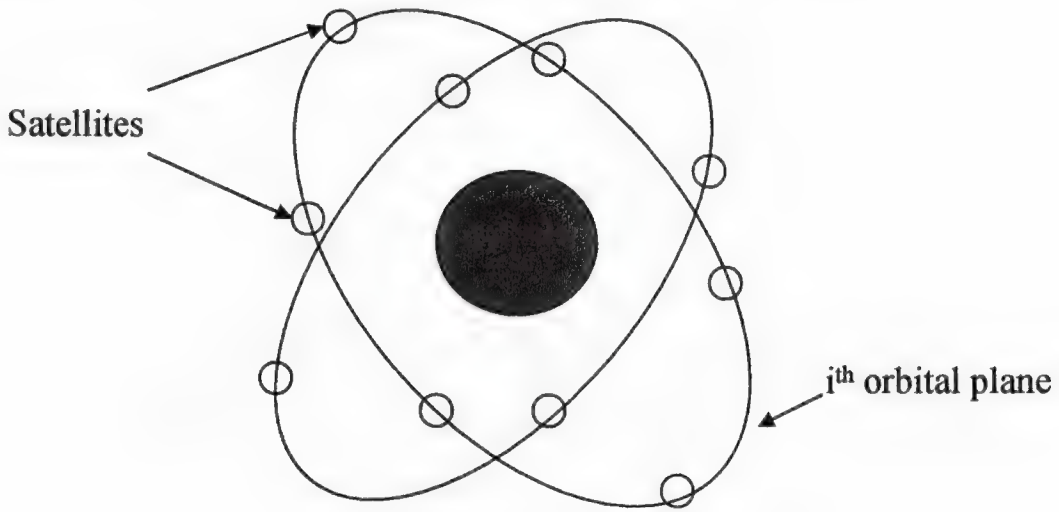
  - Because of the relatively large cells used in these systems, mobility at speeds much higher than those of ground-based vehicles is supported

Mobile Satellite Communication Systems

- Satellites for mobile communication applications have been deployed in all 3 orbits, but the LEO and MEO orbits are preferred
  - Satellites in the LEO and MEO orbits have the following advantages over GEOs for mobile communications:
    - Shorter propagation delays, and hence better service quality
    - Less power is required for hand-held user devices on the ground to "reach" the satellite
    - Smaller coverage areas allow more efficient use of spectrum (through higher frequency re-use)
    - Can truly provide global coverage
  - A major disadvantage of LEO and MEO orbits is that they require many more satellites to cover the earth, resulting in:
    - More complex space segment coordination and orbital maintenance
    - More complex network architecture (call handoffs, call routing, satellite resource management, etc)
    - Relatively long time for full network deployment

Mobile Satellite Communication Systems

- By definition, LEO and MEO satellites cannot remain stationary relative to the earth
  - Satellites must move very rapidly to stay in orbit (i.e. to avoid crashing down to earth due to strong gravitational pull)
    - This means that "cells" created by these satellites do not appear stationary relative to users on the earth
  - These systems therefore require the use of multiple well-coordinated satellites to provide uninterrupted communication service as they move across the earth
    - Multiple orbital planes, each with multiple satellites, are necessary

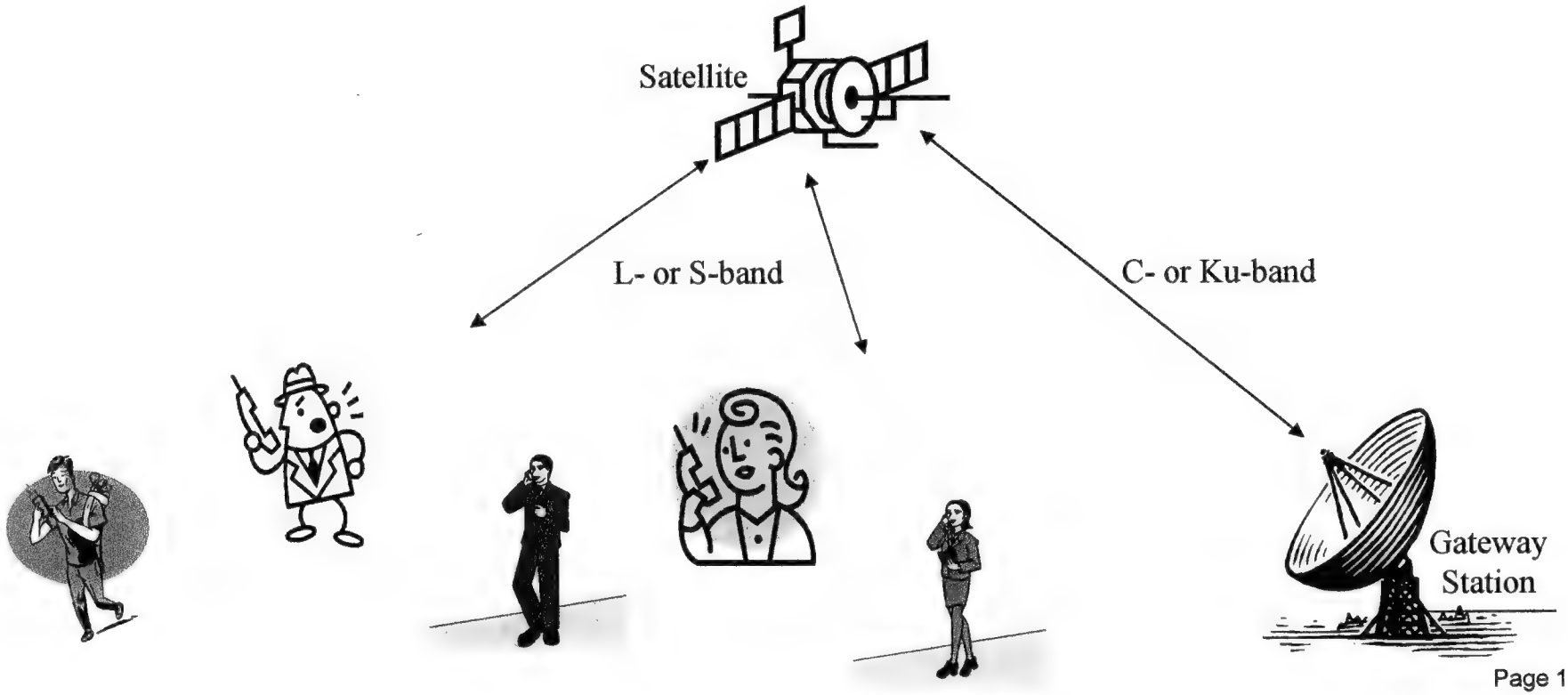


Mobile Satellite Communication Systems

- MSS systems generally use frequency spectrum in the C- and Ku-bands for the *feeder link* and the L- and S- bands for the *service links*

L-band spectrum: 1.5 – 1.6 GHz

S-band spectrum: 2.0 – 2.5 GHz



Mobile Satellite Communication Systems

- Mobile satellite communication systems are being used to provide services in all three user environments: land, sea and air
- The INMARSAT system is probably one of the most important MSS systems for travelers
  - It provides global communications and safety-related services to maritime, land and aeronautical vehicles, via a constellation of four GEO satellites (Indian Ocean Region, AOR (E), AOR (W), and Pacific Ocean Region)
    - Currently supports digital voice and data transmission at rates up to 64 kbps; next generation services planned to include rates up to 432 kbps
    - System is also used as part of the Global Maritime Distress and Safety Service (GMDSS)
    - Aeronautical services include support for cockpit communications, air traffic control, and operational and administrative communications
  - Newest generation of satellites include a navigation transponder for enhancing the accuracy, availability and integrity of GPS and GLONASS signals
  - Network Operations Center located at Inmarsat headquarters in London, UK

Mobile-Satellite Communication Systems

- Other representative MSS systems include:
  - AMSC (American Mobile Satellite Corporation)
    - A regional GEO-based system providing MSS digital voice and data services (up to 4.8 kbps) in the US
    - Uses six beams for coverage of CONUS, Canada, Hawaii, the Caribbean Basin, and offshore territorial waters to 200 miles
      - Partnered with Telesat Mobile of Canada for the space segment procurement
  - EUTELTRACS
    - A regional GEO-based system operated by the European Telecommunications Satellite Organization (EUTELSAT)
    - Supports an integrated message exchange and position reporting service, at 9.92 kbps
  - ACes (Asia Cellular Satellite System)
    - A regional GEO-based system providing digital voice and data services
    - Coverage is in the region encompassing China and Japan to the north, Indonesia to the south, the Philippines to the east, India and Pakistan to the west

Mobile-Satellite Communication Systems

- Other representative MSS systems (cont'd):
  - ICO (Intermediate Circular Orbit)
    - A global MEO-based system developed by New ICO, an affiliate company of Inmarsat created in 1995 to implement a personal communication system
    - Space segment consists of 10 satellites in two 45° inclined orbits
    - Provides digital telephony and data services (up to 4.8 kbps), and a suite of messaging services
  - Globalstar
    - A global LEO-based system developed by Loral Aerospace and Qualcomm for the Globalstar consortium
    - Space segment consists of 48 satellites in eight inclined orbits; each satellite has 16 spot beams
    - System provides digital voice and data services (up to 9 kbps); targets rural areas
    - Uses CDMA technology

Mobile-Satellite Communication Systems

- Other representative MSS systems (cont'd):
  - ORBCOM
    - A global LEO-based system developed by Orbital Sciences Corporation in alliance with Teleglobe Canada
    - Space segment consists of 36 satellites
    - System provides low bit-rate 2-way data communication services (up to 56 kbps) in the VHF band (137 – 150 MHz), primarily to customers in remote areas
      - VHF band permits very low-cost technology to be used; less than $2 M per satellite
  - ELLIPSO
    - A global hybrid (LEO/MEO) orbit system intended to provide mobile and fixed telephony services to users whose needs are not being served by existing systems
      - Target market is offshore mining and exploration sites, mountaineers, emergency services, cross-country transportation fleets, private aviation, etc.
    - Space segment to consist of 16 satellites in a combination of elliptical (Borealis) and circular (Concordia) orbits
    - Uses CDMA technology

Mobile-Satellite Communication Systems

- Other representative MSS systems (cont'd):
  - Iridium
    - Worthy of mention due to its innovative design, although no longer operational
    - A global LEO-based system intended to provide mobile telephony and data services (up to 4.8 kbps)
    - Space segment originally designed for 77 satellites in 7 orbital planes, later scaled down to 66 satellites in 6 orbital planes; each satellite had 48 spot beams
      - Satellites supported on-board switching, allowing inter-satellite links within a plane
    - User handsets designed for dual-mode operation with the major terrestrial digital cellular standards (GSM, cdmaOne, PDC, D-AMPS)
      - Customers would use a partner cellular system if within range, otherwise be served through satellite
    - Used Ka-band for the feeder link with TDMA; TDD for the service links
    - Started in November 1998, went into bankruptcy shortly afterwards

Session 7:

Radio Paging and Messaging Systems

Outline

- Introduction
- History of Radio Paging
- More Recent Developments in Radio Paging
  - Satellite Paging
  - European Radio Messaging System (ERMES)
  - FLEX
  - Two-way Paging
- Wide-Area Mobile Messaging Systems
  - RAM/Mobitex Network
  - ARDIS/Modacom Network
  - Cellular Short Message Service (SMS)
  - i-Mode

Introduction

- Radio paging and wireless messaging systems are used for data rather than voice communications
  - Paging systems typically handle very brief message transmissions over a local or wide area
    - Until recently, paging systems were simplex communication systems, with transmissions always going one-way to the service subscriber
    - Two-way paging service (also known as *interactive paging*) is now available, allowing messages to be sent upstream from capable subscriber devices
      - Devices which can only send back receipt acknowledgements are generally referred to as 1.5-way paging devices
      - Those that can return preset responses are referred to as 1.7-way paging devices
      - Those that allow the user to type in a response message via a keyboard are referred to as full 2-way paging devices
  - Wireless messaging systems are two-way data communication systems which support the transmission of much longer messages
    - Typically used to access corporate intranets and public data networks

History of Radio Paging

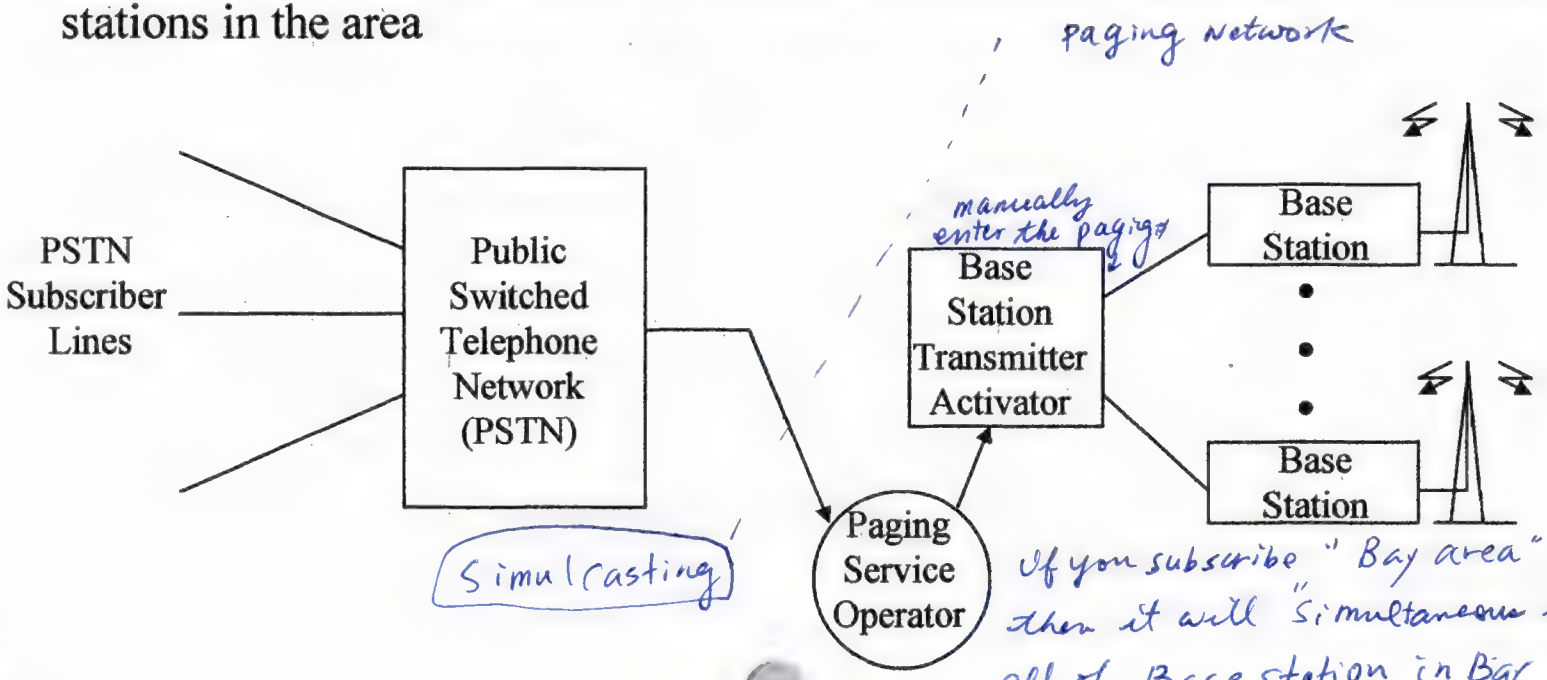
- Radio paging is one of the oldest and probably the simplest of all major organized mobile radio services
  - First systems were deployed around 1956, initially as private systems in hospital compounds, quickly adopted by large corporations
    - Systems used *alert-only* pagers
      - A simple beep would alert the user who would then call the paging service operator to learn specifics of the page
    - The earliest systems used *tone coding* for addressing user devices
      - In the 2-tone coding scheme, two tones were sent from a pool of 30 tones
        - » This permitted 870 unique addresses per system
      - Codes were transmitted over a 35 kHz carrier
        - » Coding tones were used to modulate the carrier
  - Enhancements were later made to the coding scheme to increase system capacity
    - The 2-tone scheme was expanded to use a pool of 70 tones
      - This expanded subscriber capacity to nearly 5,000 per system

History of Radio Paging

- Notable advancements in radio paging technology occurred in the late 1950's
  - Systems were enhanced to support *tone-plus-voice* paging
    - Callers were able to record short audio messages (up to 10 msec long) which could be sent to the called party along with the beep alert
  - A 5-tone coding scheme was introduced to extend the system capacity to about 100,000
    - This made possible the development of wider-area paging systems
- The tone paging systems had some undesirable shortcomings
  - Systems were prone to false addressing (hence, false alerts)
    - Primarily due to inaccuracies of tone detection circuitry inside pagers
  - Systems offered no privacy to called party
    - Voice messages sent along with the alert would be played soon after the alert is received, with no privacy control by the recipient
  - Coding schemes were limited and unsuitable for complex messages using alphanumeric text

History of Radio Paging

- The first wide-area paging systems were deployed in the US and Canada in the early 1960's
  - Systems used binary digital addressing schemes instead of tone coding
  - Initially, callers had to go through a paging service operator (PSO)
    - PSO would collect the called party's number and a numeric message (call-back number)
    - PSO would then simultaneously broadcast (*simulcasting*) the page on all base stations in the area

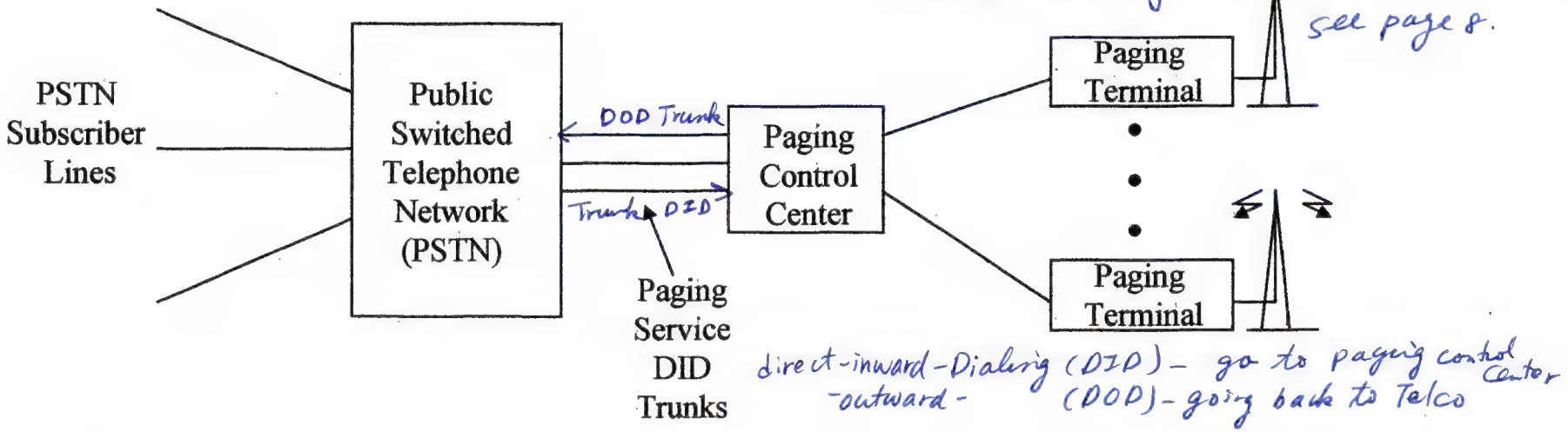

paging network
PSTN Subscriber Lines
Public Switched Telephone Network (PSTN)
manually enter the paging #
Base Station Transmitter Activator
Base Station
Base Station
Paging Service Operator
simulcasting
If you subscribe "Bay area" then it will "simultaneous broadcasting" all of Base station in Bay area.

History of Radio Paging

- Later, *paging control centers* (PCCs) were introduced which automated the operator function and allowed direct dialing of the desired pager number
  - Callers dialing a pager number would be automatically routed to the PCC
  - The PCC would collect the called number, prompt the caller for a numeric message, store the information, then transmit pages in batches using "simulcasting"

(Don't send one page message carry many pages in one message)

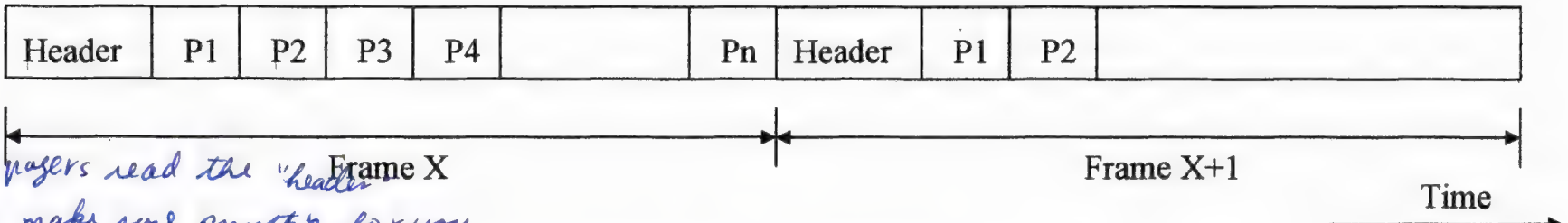
see page 8.



- The above paging system architecture is essentially what continues to be used today, with the addition of DOD trunks to support two-way paging capability

History of Radio Paging

- In the batch transmission scheme, each paging frame contains many individual pages
  - Information contained in the frame header enables each pager to determine whether or not there is a page addressed to it in this frame



all pagers read the "header" and make sure anything for you otherwise go to "sleep" mode. waiting for the new page message.

- When a pager determines that no page is forthcoming in this frame, it enters a "sleep mode" until the beginning of the next frame
  - Sleep mode of operation is one reason pagers can stay for a long time without requiring battery change

There is some "delay".

- Each paging terminal continuously transmits a constant length paging frame
  - This is so as to provide a frame synchronization signal for pagers in the area
- In a typical system, paging frames are repeated multiple times to ensure near 100% reception of all pages

History of Radio Paging

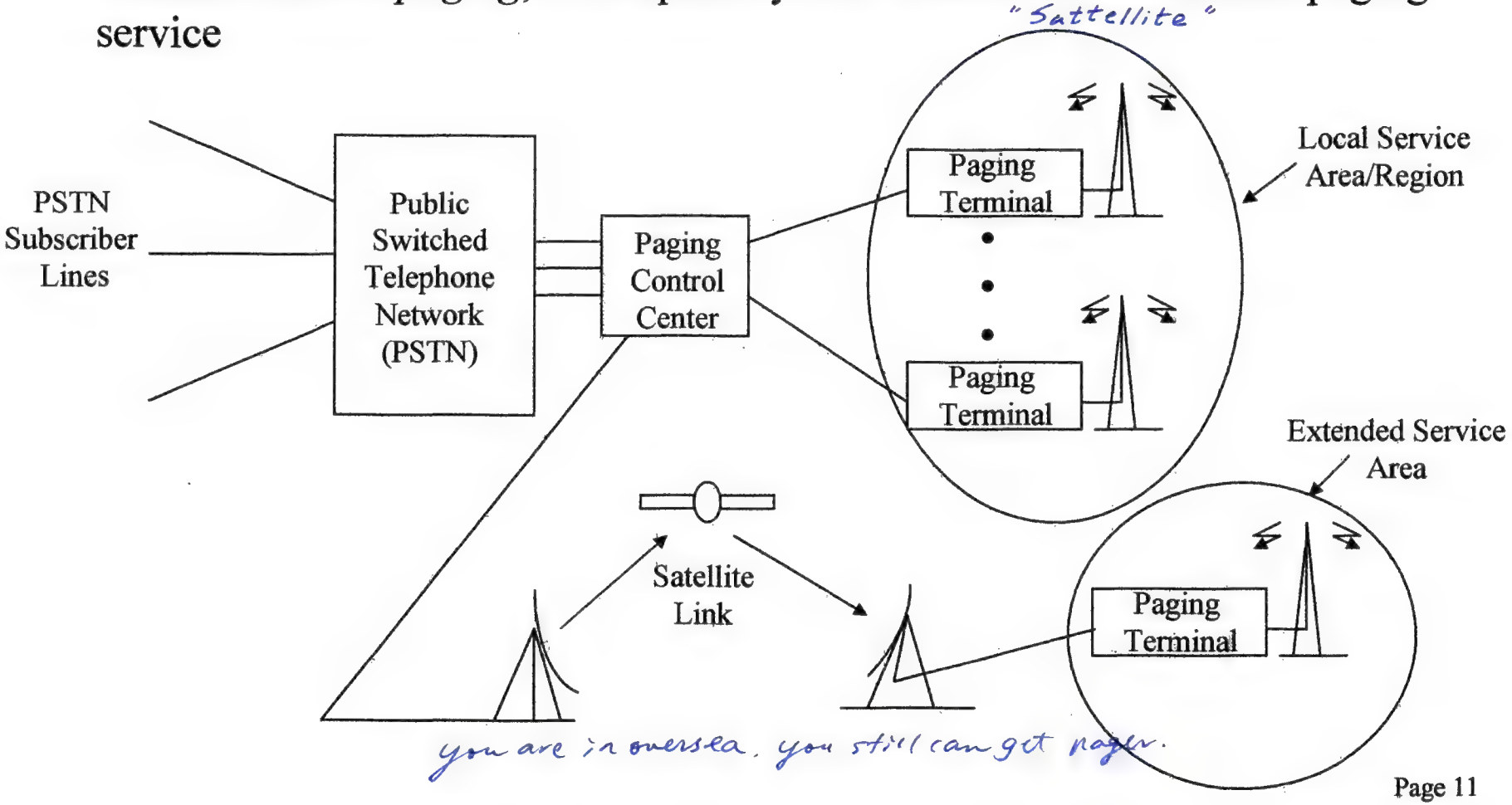
- In Europe, wide-area paging systems were first introduced in the Netherlands and Belgium (1964) and Switzerland (1965)
- Many binary digital addressing schemes for paging systems were developed in the 1960's
  - Europe, Japan and the US were the major centers of these activities
    - In some countries (e.g. the UK) multiple formats were proposed, which made it difficult to roll-out compatible nationwide service
    - In some other countries (e.g. Japan) multiple frequencies were used in different parts of the country (districts) to avoid interference
      - This also made it difficult to deploy a nationwide service
  - Of all the earlier binary schemes, only the Motorola *Golay Sequential Code* (GSC) and NEC's *D3* coding formats are still in use today
    - Motorola has historically been the predominant manufacturer of paging system products and pagers
      - Recently, Motorola licensed its manufacturing of paging system products to Glenayer Communications

History of Radio Paging

- In 1976, the British Post Office (now BT) spearheaded an industry effort to develop a common coding standard for paging systems
  - Manufacturers from all around the world were invited to participate in the *Post Office Code Standardization Advisory Group* (POCSAG)
  - The standard which emerged from this effort became known in the industry as the POCSAG coding standard
    - Standard included full numeric and alphanumeric message capabilities
    - It was quickly adopted by many countries of the world
- In 1982, the CCIR (now ITU-R) adopted POCSAG as its *Radio Paging Code No. 1* (RPC1) standard
  - RPC1 has an address capacity of about 8 million and can transmit at 512 and 1200 bps
  - Most countries around the world adopted the RPC1 paging format
    - In North America, both the GSC and RPC1 formats are in use, along with some other newer formats

More Recent Developments in Radio Paging

- In the mid-1980's many paging service operators began using satellites for extending coverage areas beyond a city
  - Dubbed *satellite paging*, this capability now allows near worldwide paging service

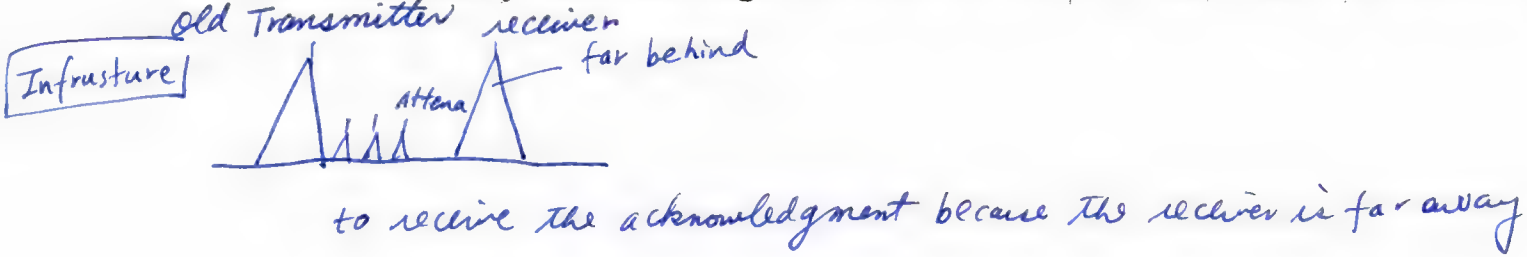


More Recent Developments in Radio Paging

- In effort to improve throughput of paging systems, the Europeans (ETSI) defined a new paging standard in 1992
  - Standard was named ERMES (*European Radio Messaging System*)
  - ERMES offers a throughput of 6.4 kbps
  - ERMES systems can be found in Europe and some parts of Asia
- In 1993, Motorola introduced the *FLEX* radio paging format
  - Like ERMES, FLEX transmits at 6.4 kbps
  - FLEX has become the most popular paging technology in the US and in all new paging system installations around the world
- With the advent of two-way paging, Motorola enhanced its FLEX technology to support two-way service
  - Enhanced technology is known as *ReFLEX*
  - REFLEX uses a 9.6 kbps rate downstream (to pagers) and a 6.4 kbps rate upstream

More Recent Developments in Radio Paging

- "Two-way paging systems" are typically "asymmetric" in network layout
  - Systems use a combination of a few wide-area broadcasting transmitters and many more receiving antennas
    - High-power antennas installed on mountain tops or high rooftops are used for transmissions to pagers
    - Lower height and a larger number of antennas are used to receive transmissions from pagers
  - This configuration allows the cost-effective coverage of a wide area without substantially increasing the cost or size of the user devices (pagers)

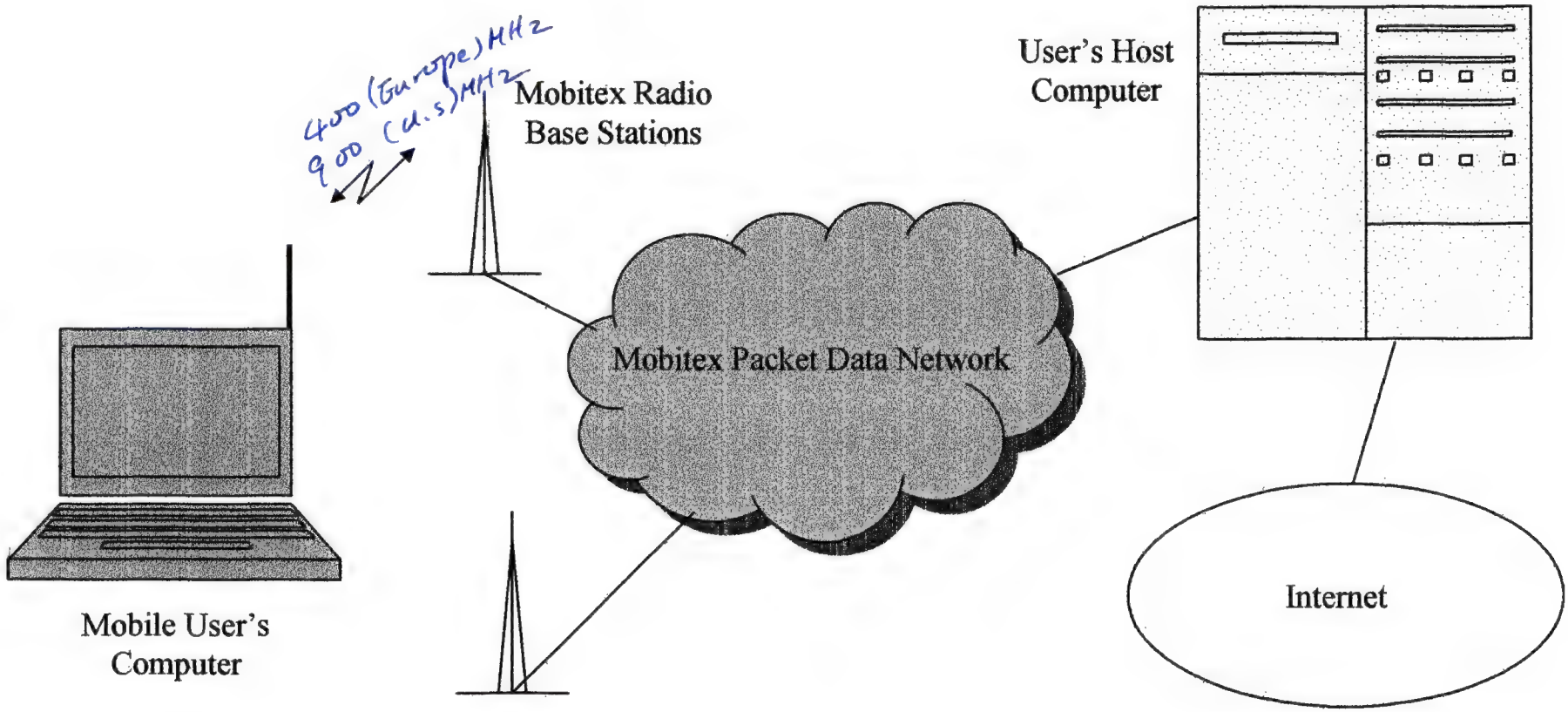


Wide-Area Mobile Messaging Systems

- Major options for sending long messages over a wide area are via:
  - Mobitex Network
  - ARDIS Network
  - Cellular Short Messaging Service (SMS)
  - i-Mode Service
- **Mobitex** is a wide-area two-way packet data network based on protocols developed by Ericsson
  - Originally developed for Swedish Telecom (now Telia)
    - Service in Sweden started in 1983
  - Mainly used to provide mobile users access to their corporate host computers and the Internet
  - Transmits at a data rate of 8 kbps
  - Can transport message packets up to 512 bytes long (i.e. about a quarter of a page of text)
    - Capacity is sufficient for a typical short e-mail message or fax transmission
  - Supports connectivity to TCP/IP, X.25, SNA, DECNet host environments

Wide-Area Mobile Messaging Systems

- Mobitex systems are now operational in many countries of the world
  - European Mobitex systems operate in the 400 MHz frequency band; those in the US are deployed in the 900 MHz band of the SMR spectrum allocation



Wide-Area Mobile Messaging Systems

- Outside the US, Mobitex systems have been deployed in many countries in Europe and Asia
- In the US, Mobitex service was introduced by a consortium of companies led by Bell South
  - Networks in the US are currently primarily operated by RAM Mobile Data, a subsidiary of Bell South good coverage in East. not West of U.S.
  - Most of the eastern part of the US has Mobitex coverage; spotty coverage in the west and mid-western states
- The Mobitex air interface protocol was initially proprietary to Ericsson but has since been made an open protocol
  - Channel access is via slotted ALOHA
  - Many value-added developers have developed applications and enhanced the system's capabilities beyond the original Ericsson offering
    - In the late 1990's, RIM (Research in Motion) developed a radio modem for support of 2-way e-mail and Internet access (e.g. Blackberry, etc0
    - Palm Computing and Handspring have developed internal radio modems for interfacing their PDAs (Personal Digital Assistants) to the Mobitex network

Wide-Area Mobile Messaging Systems

- **ARDIS** (*Advanced Radio Data Information System*) is a wide-area data network based on protocols developed by Motorola
  - System was developed by Motorola in 1990, originally for IBM's internal use
    - Its original purpose was to provide connectivity for IBM field service personnel
    - ARDIS was created as a joint venture between IBM and Motorola, however Motorola later bought out IBM's interest
  - System works much like the Mobitex system, except it operates in the 800 MHz band and can transmit at up to 19.2 kbps
  - System is based on Motorola's MDC 4800 and RD-LAP protocols
    - Although protocols have been made open, there haven't been many third-party products developed for ARDIS
  - ARDIS has been in operation in the US much longer than Mobitex
    - Because of its origin as a network for IBM field service personnel, system coverage is available in most US cities and major towns
  - Outside the US, ARDIS systems are in use in Europe and Asia as well
    - In some countries, ARDIS is called Modacom

Wide-Area Mobile Messaging Systems

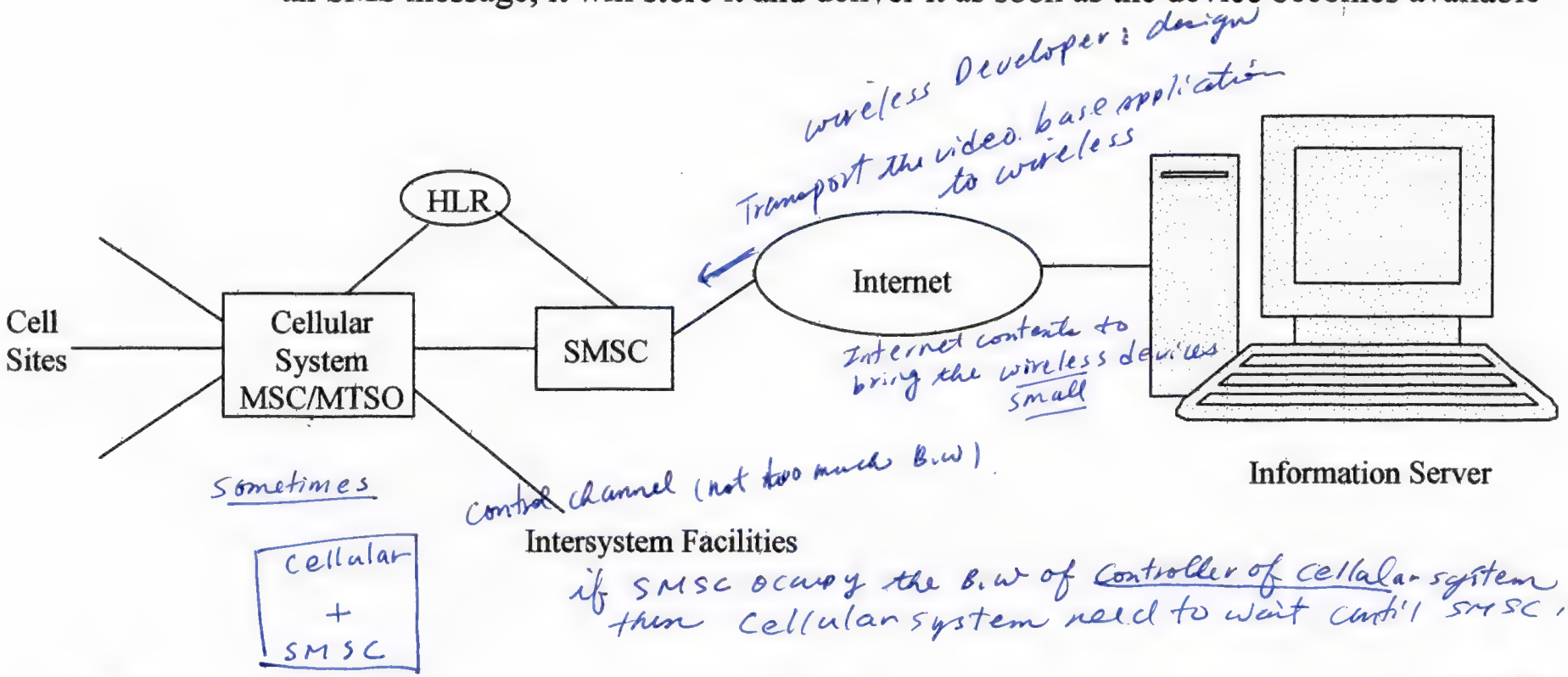
- Cellular short messaging service (**SMS**) is currently the most popular wireless messaging service in the world
  - It allows users of cellular mobile service to send and receive basic text messages between each other using SMS-capable phones
    - SMS messages are transported over the cellular system's control channels
  - SMS was first incorporated into the GSM digital cellular standard
    - First recorded SMS message transmission was on December 1992 through Vodafone's network in the UK
    - SMS use exploded in Europe even though service providers did not actively promote the service
      - SMS costs were much lower than a one-minute voice call; main users were teenagers using prepaid service contracts
      - Low wireline Internet penetration has also been cited as a factor in SMS popularity in Europe
  - SMS was not introduced in the US until late 2000
    - Primarily because the feature had not been incorporated in earlier versions of the US digital cellular standards (cdmaOne, D-AMPS)

Wide-Area Mobile Messaging Systems

- Main uses of SMS currently are:
  - Person to person messaging
    - By far the largest application; most popular among the youth
  - Notifications of voice and fax mail
  - Information services (weather and news)
  - Mobile banking and payment
  - M-commerce
    - For example, in Austria, SMS has been used to facilitate the purchasing of tickets by passengers while traveling on the train instead of waiting in lines
  - Enterprise advertising
    - For example, in Italy, Dunkin' Donuts has used SMS to advertise doughnut specials
  - Ring tones
    - Nokia uses SMS to enable cellular service users to change the way their mobile phone rings
    - This application has become quite popular because people use it to personalize their phones
- SMS on GSM, D-AMPS and PDC networks supports message lengths up to 160 bytes; cdmaOne networks support messages up to 256 bytes

Wide-Area Mobile Messaging Systems

- Cellular networks offer SMS service through use of the Short Messaging Service Center (SMSC)
  - The SMSC is a central *store-and-forward* facility that accepts, buffers, processes, and distributes all SMS messages in a network
    - If the recipient's wireless device is not available when the SMSC attempts to deliver an SMS message, it will store it and deliver it as soon as the device becomes available


wireless Developer : design
Transport the video base application to wireless
HLR
Internet
Cell Sites
Cellular System MSC/MTSO
SMSC
Internet contents to bring the wireless devices small
Information Server
Sometimes
Control channel (not too much B.W)
Intersystem Facilities
Cellular + SMSC
if SMSC occupy the B.W of Controller of cellular system then Cellular system need to wait until SMSC is clear

Wide-Area Mobile Messaging Systems

- Adoption of SMS in North America has not been as high as witnessed in Europe and some other parts of the world
  - Some of the reasons given for this low adoption rate are:
    - North America has high PC penetration, with faster network speeds and larger color screens
    - The time away from a computer is short
      - Most people have computer access at work and at home, reducing the need for SMS while traveling
    - Low cost local telephone calls have spurred home landline Internet usage
    - Inputting text is still difficult
    - SMS roaming in North America is limited
    - North Americans still prefer voice interaction on a mobile device (voice communication is quicker)

Tq protocol - (Tegic)

Wide-Area Mobile Messaging Systems

- i-Mode is a packet-switched wireless Internet service invented by Japan's NTT DoCoMo
  - Launched in February 1999, it has had runaway success in Japan
    - It is estimated that there are over 10 million i-Mode users in Japan, and the number is growing at around 50,000 new users each month
  - i-Mode was first deployed on DoCoMo's PDC digital cellular network, later also offered on the company's PHS system
  - The huge success of i-Mode has been attributed to the following factors:
    - DoCoMo did extensive market study and worked with manufacturers to develop appealing user devices featuring large screens and color graphics
    - i-Mode uses a subset of HTML (called C-HTML), which makes it easier for web application developers to modify their web software for i-Mode
    - DoCoMo made the decision to act as the ISP for i-Mode users
      - Users are provided an e-mail account along with their subscription
    - DoCoMo set itself up as the portal to the i-Mode service
      - Initially acted as aggregator of rich content from a wide range of content providers
      - Now allows i-Mode users to access any i-Mode compatible Internet site

Session 8:

Wireless Local Area Networks (WLANs)

OUTLINE

- Introduction to Local Area Networks
- Wireless Local Area Networks
- The IEEE 802.11 Physical Layers
- Other Major WLAN Standards
  - Home RF Standard
  - HIPERLAN Standard
  - HiSWAN Standard

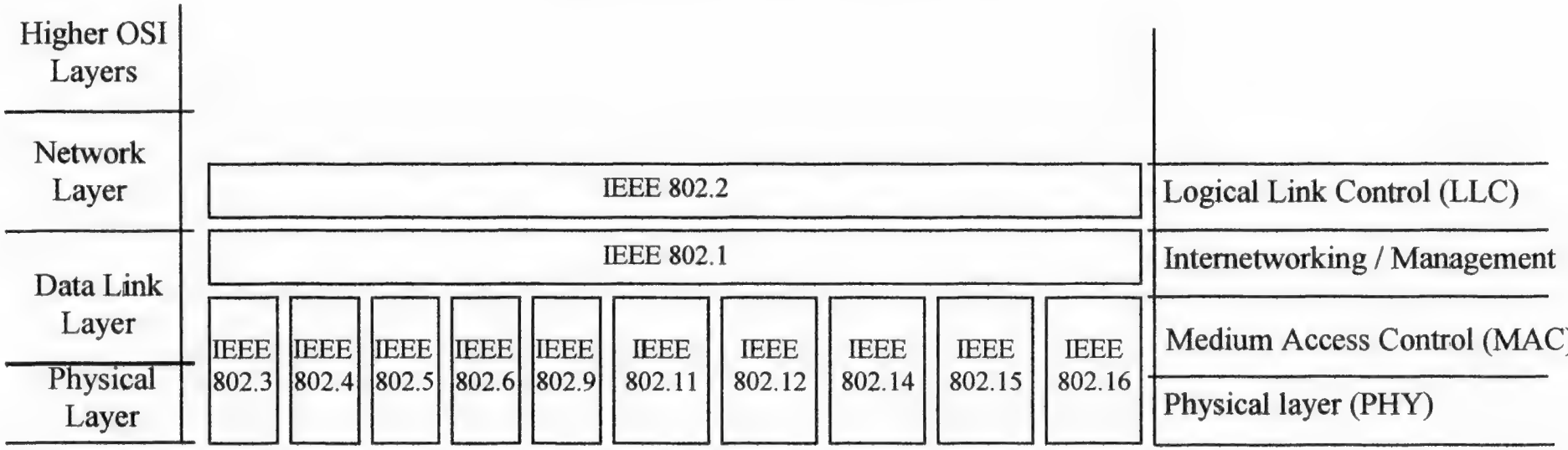
Introduction to Local Area Networks

- A *local area network* (LAN) is a high-speed data communication network used to interconnect independent computers and associated network resources within a limited geographic area
  - LANs can be deployed in office environments, inside private homes, or within a complex of buildings in close proximity (e.g. a campus)
  - Network elements typically include PCs, servers, and peripheral components such as printers
- LANs allow the interconnected devices to share network resources and to exchange information at high speeds
- Because a LAN is usually owned and operated by one organization, LANs are not constrained by national or international standards
  - Consequently, many different varieties of proprietary LANs have evolved over the years

Introduction to Local Area Networks

- The IEEE 802 family of standards defines a reference model and a set of standards for the most significant classes of LANs, MANs, WANs, and PANs

IEEE 802 Reference Model



Introduction to Local Area Networks

- IEEE 802.1: Internetworking and Network Management Sublayer
  - A sublayer developed specifically for LANs; not part of the OSI model
  - Defines the operation of MAC bridges, including their remote operation
  - Defines an architecture and protocols for virtual bridged LANs
  - Specifies network management information and procedures that apply across the IEEE 802 family of standards
- IEEE 802.2: The Logical Link Control (LLC) Sublayer
  - Another LAN-specific sublayer
  - Primary function is to provide a common interface to the Network layer while allowing for multiple Physical layer topologies
  - It is responsible for ensuring error-free transfer of frames from source to destination (over the Physical layer)
  - Protocols apply across all IEEE 802 family of standards

Introduction to Local Area Networks

- IEEE 802 MAC and PHY standards:
  - 802.3: Ethernet LAN Standard
    - *CSMA/CD Access Method and Physical Layer Specifications*
      - » Specifies a physical layer protocol for Ethernet networks
    - Original Ethernet, developed in 1976 by Xerox, transmitted at 10 Mbps; IEEE 802.3 provides for various data rates up to 1 Gbps
  - 802.4: Token Bus LAN Standard
    - *Token-Passing Bus Access Method and Physical Layer Specifications*
      - » For networks using bus topology and token-passing for access control
    - Supports data transmission speeds up to 20 Mbps
  - 802.5: Token Ring LAN Standard
    - *Token-Passing Ring Access Method and Physical Layer Specifications*
      - » For networks using ring topology and token-passing for access control
    - Supports data transmission speeds up to 16 Mbps

- IEEE 802 MAC and PHY standards (cont'd):
  - 802.6: Metropolitan Area Network (MAN) Standard
    - *Distributed Queue Dual Bus (DQDB) Access Method and Physical Layer Specifications*
      - » Specifies a physical layer protocol for DQDB sub-networks supporting different telecommunication services (high-speed data, voice, and video) throughout a metropolitan area
  - 802.9: Integrated Services LAN Standards
    - *Integrated Services LAN Interface at the Medium Access Control and Physical Layers*
      - » Defines a unified access method for a LAN providing integrated voice and data services to the desktop
  - 802.11: Wireless LAN Standards
    - *Wireless LAN Medium Access Control and Physical Layer Specifications*
      - » Specifies the standards for wireless networking

Introduction to Local Area Networks

- IEEE 802 MAC and PHY standards (cont'd):
  - 802.12: Demand-Priority Access Standard
    - *Demand-Priority Access Method, Physical Layer and Repeater Specifications*
      - » Defines a physical layer protocol that combines the simplicity and fast access of the Ethernet protocol with the stronger control, better collision avoidance, and deterministic delay features of the Token Ring protocol
    - Repeaters grant access to the requesting stations in a cyclic sequence, using a round-robin protocol according to assigned priority levels (either normal priority or high priority)
    - Transmit data rate of 100 Mbps currently; a gigabit version of the Demand-Priority protocol under development
  - 802.14: Cable Modem Standard
    - Defines a physical layer protocol for cable modem-based networks providing Internet access through cable TV distribution networks operating over coaxial cable wiring and fiber originally installed for TV signal distribution

Introduction to Local Area Networks

- IEEE 802 MAC and PHY standards (cont'd):
  - 802.15: Wireless Personal Area Network Standard
    - Defines physical layer protocols for low-power, short-range wireless networks for providing tetherless device interconnectivity
    - Includes both low-speed (< 200 kbps) and high-speed (10-55 Mbps) WPANs, as well as their coexistence with WLAN networks and devices in the 2.4 GHz band
    - Also formalizes the Bluetooth 1.0 Specification as an IEEE standard
  - 802.16: Fixed Broadband Wireless Access Standard
    - Defines physical layer protocols for point-to-multipoint wireless access systems operating in the 2 – 11 GHz frequency range and those operating in the 10 – 66 GHz range
    - Also defines non-interfering coexistence of BWA systems, and with point-to-point systems operating in the 2 – 11 GHz band

Introduction to Local Area Networks

- Other IEEE 802 LAN standards:
  - 802.7: Broadband LAN standard
    - Specifies the physical and electrical characteristics of a broadband cable medium for Ethernet (IEEE 802.3) and Token Bus (IEEE 802.4) 10 Mbps networks
  - 802.10: Security Standard
    - Specifies a Data Link layer security protocol for LANs and MANs
      - » Protocol is referred to as the *Secure Data Exchange protocol*
    - Supported by the *Key Management protocol* in the Application layer
    - The two protocols together provide a method for secure bridging of data across network connections

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direct sequence spread spectrum

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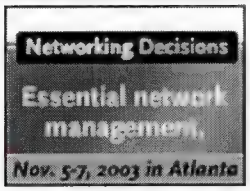

Direct sequence spread spectrum, also known as direct sequence code division multiple access (DS-CDMA), is one of two approaches to spread spectrum modulation for digital signal transmission over the airwaves. In direct sequence spread spectrum, the stream of information to be transmitted is divided into small pieces, each of which is allocated across to a frequency channel across the spectrum. A data signal at the point of transmission is combined with a higher data-rate bit sequence (also known as a *chipping code*) that divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission.

Direct sequence contrasts with the other spread spectrum process, known as frequency hopping spread spectrum, or frequency hopping code division multiple access (FH-CDMA), in which a broad slice of the bandwidth spectrum is divided into many possible broadcast frequencies. In general, frequency-hopping devices use less power and are cheaper, but the performance of DS-CDMA systems is usually better and more reliable.

Spread spectrum first was developed for use by the military because it uses wideband signals that are difficult to detect and that resist attempts at jamming. In recent years, researchers have turned their attention to applying spread spectrum processes for commercial purposes, especially in local area wireless networks.

Read more about it:

>> The Institutute for Telecommunication Sciences describes the differences between FH-CDMA and DS-CDMA.
>> SearchNetworking.com provides links to products and services that use direct sequence spread spectrum technology in wireless local area networks.

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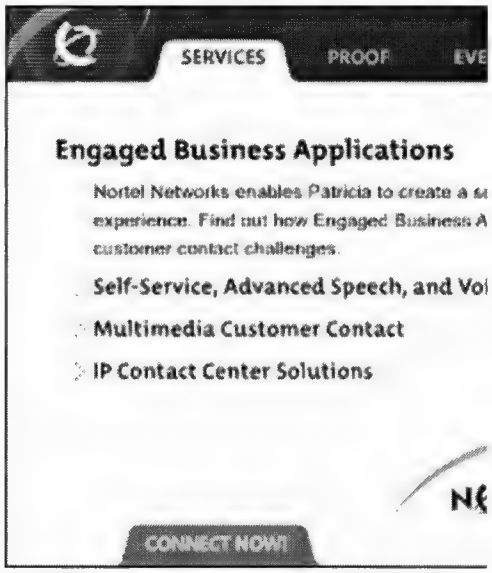

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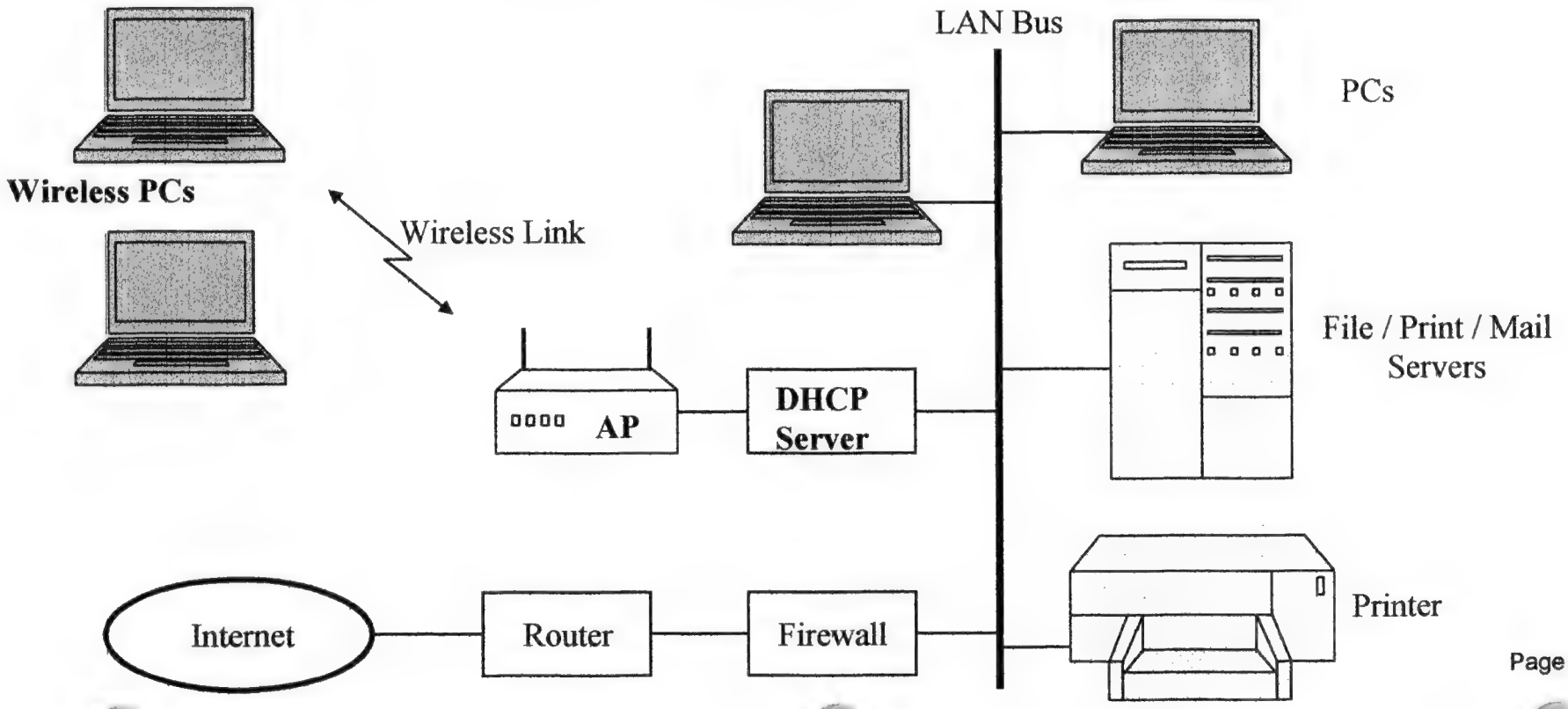
Wireless Local Area Networks

- A *wireless local area network* (WLAN) is a LAN which uses wireless technology to interconnect network elements
  - Wireless networking offers convenience and flexibility that is not possible with standard wired networks
- Stations on a wireless LAN contain a low power wireless transceiver that transmits and receives data over the wireless channel
  - Because WLANs are designed to operate in unlicensed spectrum bands, radio-based products use spread spectrum technology for the wireless link
    - Both direct sequence and frequency hoping spread spectrum techniques are used
  - Infrared-based WLANs can use direct beam and diffused beam transmission
- As in wired LANs, each computer on the WLAN can be a *client* (also called a *workstation*) or a *server*
  - A workstation is intended for use by one person at a time, whereas a server provides one or more shared services to other computers on the network

Wireless Local Area Networks

- In a typical WLAN installation, the workstations are personal computers each containing a wireless network interface card (NIC)
  - The NIC enables the PCs to communicate wirelessly with the LAN
  - Most wireless NICs come in the form of PCMCIA cards



Wireless Local Area Networks

- Typically, WLANs make use of the network's DHCP (*dynamic host configuration protocol*) server
  - The DHCP server automatically assigns an IP address to every computer on the network
    - This removes the need for manual address assignment by the system administrator
  - IP addresses are required for each computer because the protocol used for transmitting data on the network is TCP/IP
- An AP (*access point*) in a WLAN is a device used to interface the wireless stations to the wired network through the wireless link
  - As a minimum, the AP contains a wireless NIC and access point management software
    - Some vendors offer AP devices which bundle the DHCP server and router functionalities in the same box

The IEEE 802.11 Physical Layers

- IEEE 802.11 WLANs operate in three ISM frequency bands:
  - 902 MHz – 928 MHz; 2.4 GHz – 2.4835 GHz; 5.725 GHz – 5.850 GHz
  - Products deployed in the ISM bands use spread spectrum technology to allow uncoordinated co-existence with other systems sharing the bands
    - Careful system planning and frequency selection at initial installation and/or dynamic channel selection are necessary for reduced interference and optimum system performance
- IEEE 802.11 specifies five physical layer options for WLANs:
  1. Frequency Hopping Spread Spectrum (FH-SS)
  2. Direct Sequence Spread Spectrum (DS-SS)
  3. Infrared (IR)
  4. High Rate Direct Sequence Spread Spectrum (HR/DS-SS)
  5. Coded Orthogonal Frequency Division Multiplexing (COFDM)

The IEEE 802.11 Physical Layers

1. Frequency Hopping Spread Spectrum (FH-SS)

- Capable of transmitting data at 1 Mbps using a 2-level GFSK modulation, or at 2 Mbps using a 4-level GFSK modulation
- A minimum of 75 discrete hopping frequencies are typically used, each channel having a bandwidth of 1 MHz
  - In the US, this enables up to 26 FH-SS W-LAN networks to be operated in the same area

2. Direct Sequence Spread Spectrum (DS-SS)

- Capable of transmitting data at 1 Mbps using DBPSK modulation, or at 2 Mbps using a DQPSK modulation
- Typically deployed in the 2.4 GHz band using 5 MHz channels
  - A total of 11 - 14 wideband channels are available in most countries

The IEEE 802.11 Physical Layers

3. Infrared (IR)

- IEEE 802.11 infrared physical layer specifies use of diffused beam transmission in the 850 nm to 950 nm range of the infrared frequency band
  - Use of diffused beam transmission removes the need for clear line-of-sight path between the transmitter and receiver
- The IEEE 802.11 IR devices are specified to use *pulse position modulation* (PPM)
  - Sixteen position PPM (16-PPM) is employed for output data rate of 1 Mbps; and 4-PPM is used for 2 Mbps transmission
- IR WLAN links are very limited in range (no more than 10 meters), cannot penetrate solid objects, and are unsuitable for outdoor use due to interference from environmental conditions like rain and fog
  - Many consider IR as a technology for *wireless personal area networks* (W-PANs) rather than W-LANs
- There are no known WLAN products using the IR physical layer
  - However, IR technology is being used extensively as a short-range networking technology for laptops, PDAs, consumer electronics systems, and other devices

The IEEE 802.11 Physical Layers

4. High Rate Direct Sequence Spread Spectrum (HR/DS-SS)

- Introduced in 1999 as a supplement to the IEEE 802.11 standard
- Named IEEE 802.11b, HR/DS-SS is now the most widely used IEEE 802.11 physical layer
- Backward compatible with the DS-SS physical layer, and uses same 2.4 GHz band and channels
- Uses a technique called *Complementary Code Keying* (CCK) for spreading the signal, and QPSK modulation
- Enables data transmission at 5.5 Mbps or 11 Mbps, which is as fast as standard wired Ethernet (10 Mbps), over a range of up to 50 meters

The IEEE 802.11 Physical Layers

5. Coded Orthogonal Frequency Division Multiplexing (COFDM)

- Introduced at the same time as HR/DSSS, as another supplement to 802.11
- Named IEEE 802.11a, it is designed to operate in the 5GHz band using 52 channels each with a bandwidth of approximately 300 kHz
- Supports data transmission at 6 or 9 Mbps (BPSK modulation); 12 or18 Mbps (QPSK); 24 or 36 Mbps (16-QAM); and 48 or 54 Mbps (64-QAM)
- Complexity of COFDM has slowed availability of commercial products
  - Also, the fact that 802.11a devices cannot interoperate with the highly popular 802.11b products is likely to slow their widespread use for some time
- The OFDM Forum was founded in December 1999 to promote the use of OFDM in a variety of wireless applications, in addition to W-LANs
  - Founding members were Wi-LAN, Philips, Nokia, Ericsson, Samsung, Sony, and the Caltrans Testbed Center for Interoperability at UC Santa Barbara
  - Identified additional application areas include fixed wireless (MMDS / LMDS) and mobile broadband (3G / 4G cellular)
- OFDM is also being considered by IEEE 802.16 for its Wireless MAN standard

The IEEE 802.11 Physical Layers

a is not successful product

- Planned additional IEEE 802.11 physical layer:
  - IEEE 802.11g is under development as the next supplement to the IEEE 802.11 standard
    - IEEE 802.11g was originally intended to extend the transmission rate of 802.11b to 22 Mbps
    - As a result of considerable debate, the new standard will now provide backward compatibility to both the 802.11b and 802.11a standards as well
      - IEEE 802.11g therefore supports operation in both the (2.4 GHz) and the (5 GHz bands) — 802.11b, 802.11a
      - It will use COFDM for compatibility with 802.11a at speeds up to 54 Mbps, and CCK for compatibility with 802.11b systems
    - IEEE 802.11g has specified use of two optional spreading schemes for support of 22 Mbps transmission:
      - *Complementary Code Keying Orthogonal Frequency Division Multiplexing* (CCK-OFDM) technique, and *Packet Binary Convolutional Coding* (PBCC)

Backward compatible for 802.11a / 802.11b

more power.

IEEE 802.11 Physical Layers

- The Role of WECA and the Wi-Fi Standard
  - The Wireless Ethernet Compatibility Alliance (WECA) is a non-profit organization formed in 1999 by leading manufacturers of WLAN products
  - WECA's primary purpose is to certify interoperability of IEEE 802.11a and IEEE 802.11b vendor products
    - WECA established a test suite that defines how member products are tested by an independent test lab
    - Products that pass the tests can display either the *Wi-Fi (IEEE 802.11a compliant)* or the *Wi-Fi (IEEE 802.11b compliant)* seal of interoperability
      - Wi-Fi is a trademark short for wireless fidelity
  - Most recently, the term *Wi-Fi* has been used by many in the industry to refer to WLAN systems based on the IEEE 802.11 standards
    - The designation ***Wi-Fi5*** has sometimes been used in industry publications to refer to the IEEE 802.11a systems
      - The "5" is in reference to the 5GHz band of operation of IEEE 802.11a systems

Other Major W-LAN Standards

1. HomeRF Standard

- The HomeRF Working Group was formed in 1998 to develop and promote specifications for wireless networking in private homes and small offices
  - Original members included Compaq, HP, IBM, Intel, and Microsoft
    - Current membership stands at about 70 companies, including Siemens, Motorola, National Semiconductor, Proxim, Cayman Systems, Pace, and Scientific Atlanta
- The HomeRF WG released version 1 of its *Shared Wireless Access Protocol* (SWAP 1.0) specification in January 1999
  - The standard uses the 2.4 GHz ISM band and FH-SS technology
    - It uses 75 hopping frequencies and a hopping rate of 50 hops/sec
  - It supports data transmission at a rate of 0.8 Mbps using binary FSK modulation, and at 1.6 Mbps using 4-FSK
  - SWAP 1.0 systems also support up to four full-duplex voice connections
    - It uses TDMA technology based on the European Digitally Enhanced Cordless Telephone (DECT) standard; 32 kbps voice, ADPCM modulation
  - Systems have a range of approximately 50 meters

like 802.11a but speed is 2.4GHZ

Other Major WLAN Standards

BWA - Fixed wireless Broadband wireless network

1. HomeRF Standard (cont'd)

- The HomeRF WG released its SWAP 2.0 specification in mid-2001
  - Version 2 HomeRF products support transmission at 5 Mbps and 10 Mbps
    - This is comparable to the speed of IEEE 802.11b products
    - The HomeRF 2.0 products can operate at lower rates for an extended range, if desired
  - Products suppport eight full-duplex phone lines, and allow roaming between access points
  - Version 2 products are backward compatible with the installed base of SWAP 1.0 devices
- The WG has announced that it is developing a HomeRF 3.0 standard
  - HomeRF 3.0 is expected to support data rates of 40 Mbps initially, and 100 Mbps in the future
- HomeRF products are fairly popular in the marketplace, and are considered by many as the real competitor to IEEE 802.11b products at this moment

Other Major WLAN Standards

2. HIPERLAN Standard

- The *High Performance Radio LAN* (HIPERLAN) standard was developed by ETSI in the mid-1990s to provide capability similar to IEEE 802.11
  - HIPERLAN/1 products were designed to operate in the 5.2 GHz and 17.1 GHz frequency bands, and to support user data rates of up to 20 Mbps
    - Use of the higher frequencies resulted in higher component costs and shorter range than emerging 2.4 GHz systems like HomeRF and IEEE 802.11
    - HIPERLAN/1 was really never accepted in the marketplace
- HIPERLAN/2 has emerged as the next generation European WLAN standard
  - The standard was developed under the *Broadband Radio Area Network* (BRAN) project of ETSI, and was released in February 2000
  - The HIPERLAN/2 physical layer is almost identical to that of IEEE 802.11a
    - HIPERLAN/2 has been specified to operate in the 5 GHz ISM band, and will support user data rates of up to 54 Mbps
    - It is deigned to provide high speed wireless access to ATM, IP, and 3G cellular networks
  - It specifies use of transmission power control (TPC) and dynamic frequency selection (DFS) for better spectrum utilization and reduced interference

Other Major WLAN Standards

2. HIPERLAN Standard (cont'd)

- The HIPERLAN2 Global Forum was formed in 1999 to promote use of HIPERLAN/2 products
  - Founding members were Nokia, Tenovis, Dell, Ericsson, Telia, and Texas Instruments
- Production and commercial use of HIPERLAN/2 systems has been stalled by frequency spectrum harmonization issues in Europe
  - The European spectrum regulations for 5GHz WLANs are yet to be finalized
    - European standards specify the 5.25 – 5.35 GHz band for indoor use at up to 200 mW power, and the 5.47 – 5.725 GHz band for indoor/outdoor use at up to 1W power
  - A major problem is that the proposed 5 GHz WLAN band conflicts with radar operations in some areas of Europe
  - Prototype systems based on the HIPERLAN/2 standard were demonstrated in late 2000, but components and equipment have yet to become commercially available

Voice over IP
- Europe do it in industry
U.S do it by Cisco

Other Major WLAN Standards

3. HiSWAN Standard

- In Japan, the *Multimedia Mobile Access Communication* (MMAC) Project has been developing a WLAN standard called HiSWAN
- It is being designed to operate in the 5 GHz ISM band, and expected to support data rates up to 25 Mbps
- Recent adoption of Wi-Fi systems by some of Japan's largest telecommunication service providers raises questions on the eventual fate of HISWAN products

MAC-Bridging

ATM- Support Asyl syeronous traffic
- can manage the traffic in the Sonet pipe
- partition the B.W

Session 9:

Emerging Personal Area Networks and Bluetooth Technology

Outline

- The Bluetooth Concept
- The Bluetooth Special Interest Group
- Bluetooth Technology Overview
- The IEEE 802.15 W-PAN Standards
- Bluetooth Profiles
  - System Profiles
  - Service Profiles

The Bluetooth Concept

- *Bluetooth* is a relatively new wireless technology, first proposed by Ericsson in 1994
  - It was envisioned as a low cost, low power, short-range radio technology for replacing cables in mobile phone handsets, PCs and PDAs
    - Bluetooth is primarily designed to connect devices within a range of 10 meters, with optional high power operation for a range of up to about 100 meters
  - Bluetooth improves upon existing cable-replacement technology
    - Most laptop computers, PDAs, and printers today have infrared-based wireless connectivity, using Infrared Data Association (IrDA) protocol
      - IrDA was intended to allow people to print simply by pointing a computer at a printer
      - Unfortunately IrDA use never picked up, and fewer vendors now implement it
    - Bluetooth uses RF technology, removing the requirement for line-of-sight proximity of devices

The Bluetooth Concept

- Bluetooth advocates hope that the technology will embrace every electronic equipment, with diverse array of possible applications
  - Universal home remote control
    - For controlling home entertainment systems, appliances, security systems
  - 3-in-1 telephone
    - Working through regular cellular systems (non-Bluetooth)
    - Operating as cordless phones through a Bluetooth link to a nearby base station connected to the PSTN
    - Working as a walkie-talkie through a Bluetooth link to another nearby phone
  - Ultimate headset
    - Providing hands-free connectivity to cellular phones while driving
      - Voice commands used to control the phone
    - Support wireless connectivity to other compatible devices, such as computers

The Bluetooth Special Interest Group

- In February 1998, five companies (Ericsson, IBM, Intel, Nokia and Toshiba) founded the Bluetooth Special Interest Group (SIG) Inc.
  - Purpose of the SIG was to develop an open standard for always-on, short range wireless connectivity based on the original Ericsson technology
  - The core promoters group was enlarged in December 1999 with the addition of four major companies: 3Com, Microsoft, Lucent, Motorola
    - The nine core companies are referred to as the *SIG Promoters*
      - Promoters are responsible for SIG administration and for providing manpower to run the legal, marketing, and qualification processes
  - The Bluetooth SIG now includes nearly 2000 member companies
    - Main condition of membership is a requirement to allow access to each other's Bluetooth-related patents under reasonable terms
      - This is so as to prevent any company from getting a lock on the standard

Bluetooth Technology Overview

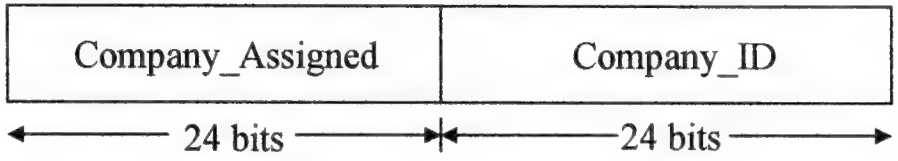
- Bluetooth-enabled devices configure themselves for communicating with each other with minimal user intervention
  - The devices automatically form informal *personal area networks* (PANs, a.k.a. *piconets*) with other Bluetooth devices in their vicinity
    - The connection of a Bluetooth device to a piconet occurs without user interaction
      - This capability is referred to as ***unconscious connectivity***
    - Each piconet has one ***master***, usually the device that first initiates the connection
      - The master ensures that only one device can transmit at a time within the piconet
    - Each device can join more than one piconet at a time
  - Up to eight devices can be directly interconnected through one piconet
    - Networks with more than 8 devices are possible, however in this case, not every device will be able to directly communicate with every other
      - Each device can only "see" the neighboring seven other devices
    - A group of piconets with one or more devices in common is called a *scatternet*

Bluetooth Technology Overview

- Bluetooth connections can be data-only, voice-only, or data and voice
  - When used for data communication, *asynchronous* connections are used
    - Bluetooth *Asynchronous Connectionless Links* (ACLs) can support symmetric data at 433.9 kbps, or asymmetric data at 723.2 kbps and 57.6 kbps
    - Since data integrity is more important than latency, packets received with uncorrectable bit errors are retransmitted
  - When used for voice communication, *synchronous* connections are needed
    - Bluetooth *Synchronous Connection-Oriented* (SCO) links provide 64 kbps (circuit-switched) voice transmission in each direction
    - Latency is guaranteed to be small through fast time-slot switching, and packets are never retransmitted
  - For data and voice communication, *isochronous* links can be used
    - The voice portion uses synchronous transmission, and data is delivered within certain time constraints but not as rigidly as in synchronous connections

Bluetooth Technology Overview

- Bluetooth devices use a set of three addresses for proper operation in a piconet:
  - ***Bluetooth Device Address:*** A 48-bit address that's unique to each device



    - The "Company_ID" field is assigned by the IEEE 802 group and is unique to each organizational
    - The "Company_Assigned" field allows each company to uniquely identify each of its Bluetooth devices
  - ***Active Member Address:*** A 3-bit address assigned by the master to slaves as they enter the piconet; address "000" is reserved for the master
  - ***Parked Member Address:*** An 8-bit address assigned by the master to "parked" active slave members

Bluetooth Technology Overview

- Bluetooth devices take on their role as master or slave in a piconet using a set of query messages:
  - *INQUIRY SCAN:* Used by a prospective slave to listen for an inquiry from a master
    - If no response is received, the prospective master assumes there is no master yet, and takes on the master role
    - If a response is received, device assumes the slave role
  - *INQUIRY:* Used by a prospective master to discover the addresses of devices in its range
  - *PAGE:* Used by a master to establish a piconet with a particular slave whose device address is known
    - Master provides enough information to the slave for proper operation in the piconet

Bluetooth Technology Overview

- The Bluetooth physical layer is based on FH-SS technology, and uses the same frequency band as IEEE 802.11b W-LAN devices (i.e. the 2.4 GHz ISM band)
  - Bluetooth radios are loosely based on the original IEEE 802.11 (FH-SS) technique
    - The hopping rate has been increased to approximately 1600 hops per second
      - This high hopping rate is almost guaranteed to cause interference to other systems in the band
      - Some in the W-LAN industry describe Bluetooth radios as "rude" radios
    - The hopping sequence is determined by a pseudorandom hop generator with a pattern which repeats after about 23.3 hours
      - The period is long to prevent accidental hop synchronization between unintended devices within range of each other

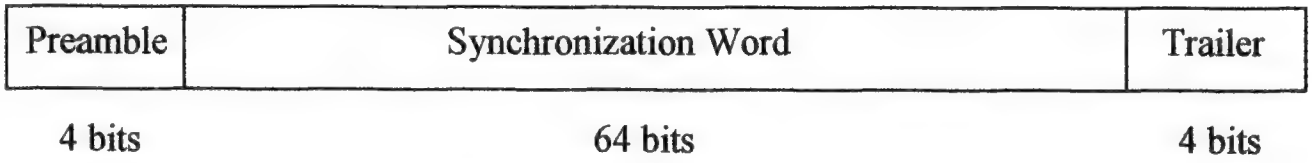
Bluetooth Technology Overview

- Each Bluetooth device is programmed to operate in a channel set consisting of 79 frequencies
  - Channels are spaced 1 MHz apart and cover the 2.402 – 2.480 GHz spectrum
  - This spectrum is available in virtually all countries of the world
    - France is the only country known to be still working on making this spectrum available to Bluetooth devices
- Bluetooth uses TDD channels with channel bandwidth of 1 MHz
  - With the chosen modulation scheme (Gaussian Frequency Shift Keying), this translates to an available channel data rate of 1 Mbps
  - FEC coding and ARQ schemes are used to achieve a channel BER of about 10^{-3}
- A generic Bluetooth packet structure is illustrated below:

Access Code	Header	Payload
68 or 72 bits	54 bits	0 - 2744 bits

Bluetooth Technology Overview

- The ***Access Code*** is used at the beginning of every packet to provide bit and word synchronization and to identify the specific Master involved with the communication



  - The Preamble is 0101 for a sync word which starts with a 0, and 1010 otherwise
  - The Trailer is 0101 for a sync word which ends with a 1, and 1010 otherwise
    - » In ACL links, the Trailer field is not used if the packet being transmitted carries no payload
  - The Synchronization Word field includes the address of the Master Bluetooth device for the piconet
  - A (64, 30) BCH block coding is used to provide FEC for the device address data

Bluetooth Technology Overview

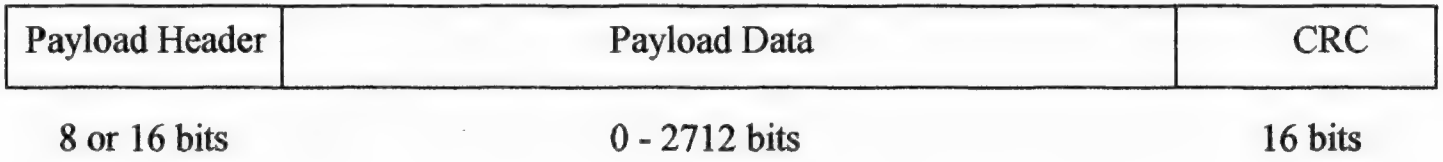
- The ***Header*** contains control information associated with the packet
  - It consists of 10 bits of control information and an associated 8-bit Header Error Check (HEC) sequence; a (3, 1) binary repetition coding results in a 54-bit long header field

AM_ADDR	Packet Type	Flow	ARQN	SEQN	Header Error Check
3 bits	4 bits	1 bit	1 bit	1 bit	8 bits

  - The AM_ADR field indicates the Active Member Address of the Slave Bluetooth device involved with the communication
    - » An AM_ADR of 000 indicates a broadcast packet from the Master to all Slaves
  - The Packet Type field indicates the type of traffic carried by this packet (SCO, ACL, NULL, or POLL), and the length of the payload (in number of time slots)
  - The Flow bit is set by a device when its receive buffer is full
  - ARQN is asserted by a device to indicate successful reception of previous packet
  - SEQN is toggled each time a new packet is sent
  - HEC is a CRC of the 10-bit header information

Bluetooth Technology Overview

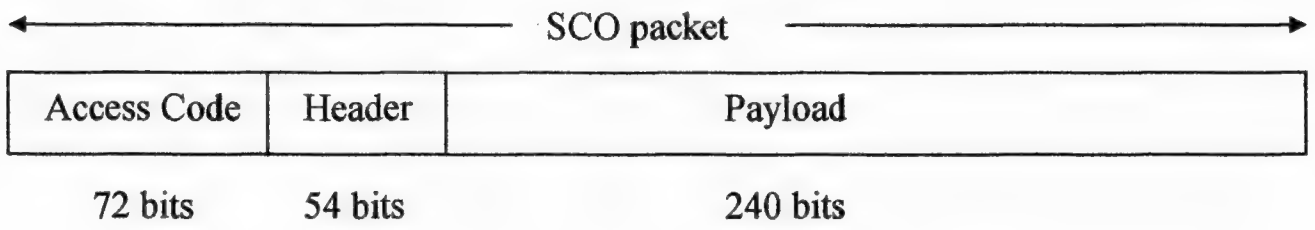
- The structure and size of the ***Payload*** field in Bluetooth systems differs with the type of traffic being carried
  - For ACL traffic, the payload field can be up to 2744 bits long (343 bytes), and is split into three parts as illustrated below:



    - » The Payload Header field includes an 8-bit Length field which indicates the length in bytes of the Payload Data field
    - » A field is also included in the Payload Header to indicate whether this packet is the start or continuation of a message
  - For SCO traffic, the size of the payload is fixed at 240 bits (30 bytes)
    - » The Payload Header field is not required in SCO links and, since retransmissions are not allowed for such traffic, so is the CRC field
    - » Flags such as Flow, ARQN and SEQN included in the packet Header of all Bluetooth transmissions are redundant and ignored for SCO traffic
    - » A (15, 10) shortened Hamming code is used for FEC on SCO packets

Bluetooth Technology Overview

- For SCO links, packet transmissions over the TDD channel are performed in 625 μsec time slots
  - A 366-bit packet is transmitted over each TDD time slot



  - Since the information payload is only 240 bits, this corresponds to a throughput of only 384 kbps (versus the 1 Mbps theoretical capacity)
  - The additional 259 μsec is used by the radio to tune to the next frequency in the hop sequence
    - No communication occurs in the piconet during the time set to perform a hop
      - » All devices on the piconet must hop together to maintain synchronization with the master
    - The "hopping" time is the primary reason for reduction in the channel throughput

Bluetooth Technology Overview

- Bluetooth uses three SCO packet types to designate three levels of quality of the service: high-quality voice level 1 (HV1), HV2, and HV3
  - For **HV1** quality, the entire 240-bit payload field is filled with speech sample bits; i.e. no FEC coding is applied
    - » To keep the data rate for voice transmission at 64 kbps, the HV1 packets in each direction are sent every six time slots (64 kbps = 384 kbps / 6)
  - For **HV2** quality, a rate 2/3 FEC coding is applied to 160 speech sample bits

Speech sample bits (160)	FEC bits (80)

    - » The HV2 packets are sent every four time slots to ensure a 64 kbps data rate
  - For **HV3** quality, a rate 1/3 FEC coding is applied to 80 speech sample bits

Speech bits (80)	FEC bits (160)

    - » The HV3 packets are sent every two time slots to maintain a 64 kbps data rate

Bluetooth Technology Overview

- For ACL links, Bluetooth has defined three packet sizes: a 1-slot packet, a 3-slot packet, and a 5-slot packet
  - The ***1-slot packet*** has a payload of 216 bits (27 bytes); uses a 625 µs slot
    - An 8-bit Payload Header is used in 1-slot packets, otherwise a 16-bit header is used
    - The associated bi-directional symmetric data rate with this packet type is 172.8 kbps (i.e. 216 bits x 800 slots/sec)
    - When rate 2/3 FEC coding is applied, the bi-directional data rate becomes 108.8 kbps
  - The ***3-slot packet*** has a payload of 1464 bits (183 bytes); over 1875 µs slot
    - The associated bi-directional data rate with this packet type is 384 kbps
    - When rate 2/3 FEC coding is applied, the symmetric data rate becomes 256 kbps
  - The ***5-slot packet*** has a payload of 2712 bits (339 bytes); over 3125 µs slot
    - The associated bi-directional data rate with this packet type is 433.9 kbps
    - When rate 2/3 FEC coding is applied, the symmetric data rate becomes 286.7 kbps
  - A maximum throughput of 723. kbps can be achieved with 5-slot packets in one direction and single-slot packets in the reverse direction at 57.6 kbps

Bluetooth Technology Overview

- For any two Bluetooth devices to communicate with each other, they must be properly synchronized as they hop between channels
  - Devices must use the same channel set
  - They must use the same channel hopping sequence
  - They must be time-synchronized within the hopping sequence
  - They must ensure that one transmits while the other receives, and vice versa
- All of these synchronization items are determined by the piconet master and passed to the slave
  - Time slots on the TDD frame are numbered with consecutive integers
  - The master transmits to the slave in even-numbered time slots, and the slave transmits to the master in odd-numbered time slots
  - In a multi-slave piconet, a slave can transmit in an odd-numbered slot only when it is specifically addressed by the master in the previous even-numbered time slot

Bluetooth Technology Overview

- Three classes of Bluetooth devices have been specified, depending on transmit power levels used:
  - Class 1 is for long range applications
    - Devices in this class can transmit at up to 100 mW (20 dBm)
    - A range of up to about 100 meters can be achieved
    - Power control is required with the high power devices to minimize level of interference to other users in the band
  - Class 2 is for medium range applications
    - Maximum transmit power is 2.5 mW (4 dBm); range of about 20 meters
  - Class 3 is for short range applications, and is expected to be the most common of all Bluetooth applications
    - Maximum transmit power for this class of devices is 1 mW (0 dBm), for a range of about 10 meters

pretty low power

Bluetooth Profiles

- The Bluetooth SIG has defined a number of ***profiles*** to be used in establishing a Bluetooth device's personality
  - A profile is essentially the application area which the particular Bluetooth device is intended to be used for
    - For example, as a wireless headset, as a wireless mouse, etc.
  - Not every Bluetooth device supports every profile, and the simplest one might support a minimum of two
  - The Bluetooth standard currently includes 13 profiles:
    - Nine service profiles and four system profiles
      - Service profiles support usage models of what a customer would expect from the device
      - System profiles include generic models for device operation in a piconet and features common to multiple applications

Bluetooth Profiles: (1) System Profiles

- There are currently four system profiles defined:
  - ***Generic Access Profile:*** establish the communication
    - The core Bluetooth profile, responsible for establishing and maintaining links between devices
    - All Bluetooth devices must include this profile
  - ***Service Discovery Application Profile:*** scanning the devices
    - Required in Bluetooth devices to discover the services supported in other Bluetooth devices
  - ***Serial Port Profile:***
    - For Bluetooth devices to emulate the RS-232or USB interface for connecting to other Bluetooth devices
  - ***Generic Object Exchange Profile:***
    - Controls how Bluetooth uses the Object Exchange client-server protocol to exchange data between devices without using Internet-style packets

Bluetooth Profiles: (2) Service Profiles

- There are currently nine service profiles defined:

Cordless Telephony Profile:

- For Bluetooth devices supporting the 3-in-1 telephone capability

Intercom Profile:

- For support of direct two-way voice communication between two Bluetooth users within range of each other
- Unlikely to be used much because of the short range of Bluetooth systems

Headset Profile:

- For Bluetooth devices to support operation of the ultimate headset

Dial-up Networking Profile:

- For Bluetooth device to serve as an Internet bridge between a computer and a cellular phone or modem which is used to dial into the Internet or other service

Bluetooth Profiles: (2) Service Profiles (cont'd)

Fax Profile:

- For Bluetooth device to emulate a fax modem when connected between a laptop computer and a cellular phone

LAN Access Profile:

- For Bluetooth devices to access LANs using PPP as well as to support PC-to-PC direct links using PPP over serial cable emulation
- Seen as potentially the most useful service profile
- SIG envisages deployment of special LAN access points in companies' premises and in busy public places such as airports and shopping malls
  - People with Bluetooth devices will be able to connect to the Internet via the special access points

802.11 I - security.

Bluetooth Profiles: (2) Service Profiles (cont'd)

Object Push Profile:

- For Bluetooth devices to be able to exchange short files that contain the same information as a regular business card, for automatic filing in a device's database

File Transfer Profile:

- Allows a Bluetooth device to access files stored on another
- Can be used by any application that needs to transfer files between devices
- In addition to linking computers, profile supports linking other devices such as MP3 players for transfer of music files, and digital cameras for transfer of image files

Synchronization Profile:

- For Bluetooth devices to support automatic synchronization of schedules and address lists between PDAs, laptops, and cell phones within range of each other

The IEEE 802.15 W-PAN Standards

- IEEE 802.15 working group was established to develop standards for wireless PANs (W-PANs)
  - ***IEEE 802.15.1:*** Standardization of the Bluetooth Specification
    - Version 1 of the standard was derived from the Bluetooth 1.0 specification which was released by the Bluetooth SIG in July 1999
  - ***IEEE 802.15.2:*** Coexistence of W-PAN and W-LAN Devices
    - Attempts to make Bluetooth and W-PAN radios less "rude" so they can coexist with IEEE 802.11 W-LAN devices that share the same 2.4 GHz band
  - ***IEEE 802.15.3:*** (High Rate) W-PAN Standard
    - Investigates increasing W-PAN data rate to at least 20 Mbps for support of some multimedia applications
  - ***IEEE 802.15.4:*** (Low Rate) W-PAN Standard
    - Investigates W-PANs for supporting data rates in the 2 kbps to 200 kbps range for low power applications such as smart cards or security tags